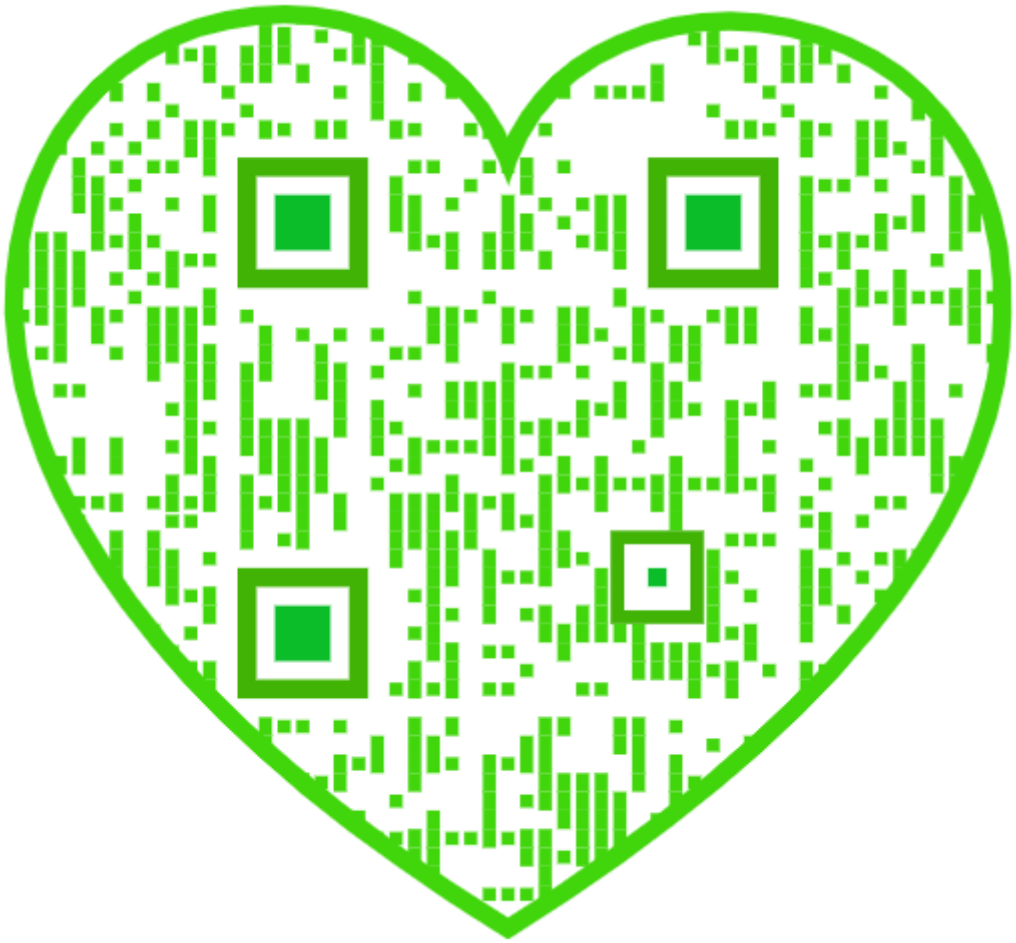

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THE ESSENTIALS OF BOTANY

BY

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Professor of Botany in the University of Nebraska

SIXTH EDITION
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PREFACE.

THE marked favor with which the first issue of this book was received, and its continuance for the subsequent editions, long ago warranted such a revision of the text as would make it conform to the later views and usage of botanical science. Certain portions of the original text have now been entirely rewritten, as, for example, that pertaining to protoplasm and the plant-cell, and the chapter on plant physiology.

The student will find many changes, also, in the treatment of the systematic part of the subject. I no longer regard the "Slime-moulds" as members of the Vegetable Kingdom, but, in deference to those botanists who still cling to them, they are discussed in an appendix to the Protophyta. In the flowering plants the arrangement given is one which has commended itself to me as a teacher of preparatory school and college students. It is certainly easily comprehended by the beginner, and is at the same time, as I think, a more nearly natural arrangement than any hitherto proposed.

Throughout this edition an attempt has been made to treat the subject in as simple and direct a manner as possible, and in so doing English or anglicized terms have been given the preference. However, when the use of a technical term makes the text plainer, it has been used without hesitation. The student will thus find a considerable

number of such terms, especially those of recent introduction, which did not appear in the former editions.

In the use of this book I must urge that it is intended to serve as a *guide* only to the teacher and student. The student must actually see as much as possible of what is here brought to his notice. The book simply marshals in logical order the objects to be studied. No doubt something may be learned by a simple consecutive reading of the paragraphs of the book, but the young botanist should not be content to obtain all his facts at second hand; he must see with his own eyes all that may be seen.

CHARLES E. BESSEY.

UNIVERSITY OF NEBRASKA, February 7, 1896.

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ESSENTIALS OF BOTANY.

CHAPTER I.

PROTOPLASM AND PLANT-CELLS.

1. Protoplasm.—The living part of every plant is a soft-ish, viscid, granular substance called protoplasm. It may be seen in ordinary plants by making thin slices of the rapidly growing parts, and then magnifying them under a good microscopee. Such a specimen is made up almost wholly of protoplasm.

2. When protoplasm is studied carefully under a high magnifying power it is found not to be a homogeneous substance; accordingly its several constituent parts have received different names, as follows:

(1) The larger mass which makes up the bulk of the protoplasmic substance is now distinguished as the *cytoplasm* (Fig. 1, *cy*), which is itself separable into (a) a more active portion, the formative cytoplasm (or *kinoplasm*), and (b) the nutritive cytoplasm, which is more abundant but less active.

(2) A rounded, usually centrally placed mass, known as the *nucleus* (Fig. 1, *n*), and composed of (a) a mass of

colorless *achromatin* (*nuclear-hyaloplasm*) making up the bulk of the nucleus; (b) a network of minute fibres (Fig. 2, *f*); (c) minute granules of *chromatin* in the network (Fig. 2, *chn*); and (d) one or more rounded bodies, the *nucleoles,* lying in the achromatin (Figs. 1 and 2, *ne*).

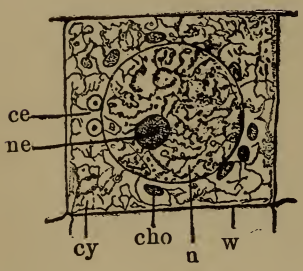


FIG. 1.—A young plant-cell magnified about 1000 diameters. *w*, cell-wall; *cy*, cytoplasm; *n*, nucleus; *ne*, nucleole; *ce*, centrospheres; *cho*, chromatophores. (From Strasburger.)

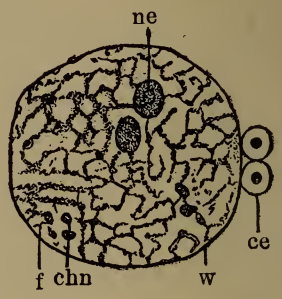


FIG. 2.—Nucleus from the embryo-sac of Fritillaria, magnified 1000 diameters. *ne*, nucleoles; *f*, fibres of fibrillar network; *chn*, chromatin granules; *ce*, centrospheres, each containing a darker centrosome. (From Strasburger.)

(3) Two small rounded bodies, the *centrospheres,* which are usually just outside of the nucleus, lying in the cytoplasm (Figs. 1, 2, *ce*). They are known also as the "directive spheres," and the granular centre of each is the *centrosome.*

(4) A number of small usually rounded bodies lying in the cytoplasm, and normally colored green (more rarely yellow or reddish), are known as the *chromatophores* (Fig. 1, *cho*).

3. Although protoplasm is so abundant, its exact chemical composition is not known. It appears to be a mixture of several chemical compounds, and contains carbon, hydrogen, oxygen, nitrogen, sulphur, besides others of less importance. Nitrogen is always present. By delicate

chemical tests some botanists have recognized the following chemical substances in protoplasm: *cytoplastin,* the essential constituent of the cytoplasm; *paralinin,* the essential constituent of the nuclear hyaloplasm; *linin,* of which the fibrillar network of the nucleus is composed; *chromatin,* of which the granules are composed; *pyrenin,* which constitutes the bulk of the nucleoles; *chloroplastin,* of which the green fibrils of the chromatophores are composed; *metaxin,* which composes the more soluble remainder of the chromatophores.

4. Living protoplasm possesses the power of imbibing food in the condition of watery solutions. The water with which plants are supplied in nature always contains a considerable amount of soluble matter, most of which is good food for protoplasm. The imbibition of watery food increases the size of the protoplasm, and this is one of the causes of growth in plants. Commonly there is a surplus of imbibed material, and this is stored in the protoplasm in the form of drops of greater or less size (the so-called *vacuoles*), thus adding still more to the distension of the protoplasm mass. (Fig. 3, *s.*)

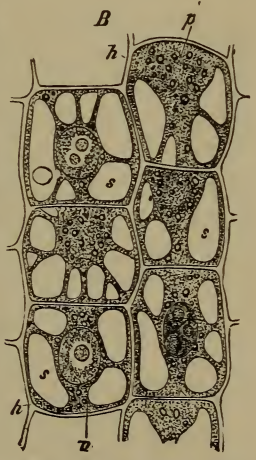


FIG. 3.—A few young cells from the root of Fritillaria, showing protoplasm (*p*), vacuoles (*s*), and thin cell-walls (*h*). Magnified 550 times.

5. The most remarkable property of protoplasm is its power of moving. Every mass of living protoplasm appears from observation to have the power under favorable conditions of changing its form, shifting the positions of its several parts, and in many instances of moving bodily from place to place.

That these movements are so generally overlooked is due to the fact that in most cases they require the aid of a good microscope, but with such an instrument the student may find evidences of motion in the protoplasm of every plant.

6. The imbibition of food, and the various movements, are affected by the temperature of the protoplasm. They take place best in temperatures ranging from that of an ordinary living-room to that of a hot summer day (20° to 35° C. = 68° to 95° Fahr.). A sudden change of temperature of even a few degrees will at once check or stop both imbibition and movement; even a sudden jarring will for a time stop both kinds of activity.

Practical Studies.—In the study of protoplasm it is necessary to be provided with a compound microscope. For convenience of working, as well as for economy, the small instruments with short tube, allowing easy use in a vertical position, are much to be preferred. The most serviceable objectives are the $\frac{1}{2}$- and $\frac{1}{6}$-inch, giving magnifying powers of from about 100 to 500 diameters. Such a microscope may be purchased in this country for from $25 to $30, and in Europe for somewhat less. A very sharp scalpel or good razor is useful in making sections. For the beginner but few reagents are necessary, viz.: 1, a solution of iodine (that made by first dissolving a very little potassic iodide in pure water and then adding iodine is the best for common use); 2, a solution of caustic potash in pure water (potassic hydrate); 3, alcohol; 4, several staining fluids, as hæmatoxylon, carmine, and safranin; 5, glycerine.

NOTE.—In the study of minute objects it is now the general custom to use metric measurements. The units used are the millimetre and the micromillimetre, the former for the larger measurements, the latter for the smaller. A millimetre equals .0394 of an inch, or nearly one twenty-fifth of an inch.

For the measurement of objects requiring high powers of the microscope the micromillimetre is used. It is represented by the Greek letter μ, or by mmm. It is one thousandth of a millimetre, and equals .0000394 of an inch, or nearly one twenty-five-thousandth of an inch. A spore is thus said to measure 15 μ in diameter, 35 μ in length, etc., or in the absence of the Greek letters we may record

these measurements as 15 mmm. and 35 mmm. In reading the foregoing we may of course say 15 micromillimetres and 35 micromillimetres, but more commonly the contraction *micron* is used, or even the name of the Greek letter: thus we may say 15 *microns*, or 15 *mu*.

(*a*) Make very thin longitudinal sections of the tips of the larger roots of Indian corn (Fig. 4); stain some with iodine, which will turn the protoplasm brown or yellowish brown; stain others with carmine; examine by the aid of the $\frac{1}{6}$-inch objective. Make similar sections of the tip of a young shoot of the asparagus.

(*b*) Make successive cross-sections of the root of Indian corn, beginning with the tip and receding five to ten millimetres. Note the vacuoles and use iodine and carmine. Make similar sections of young asparagus-stem.

(*c*) Make a longitudinal section of the young part of a petunia-stem in such a manner as to leave on each margin a fringe of uninjured hairs. Mount carefully in pure water. Examine at a high temperature (about 30° C. = 86° Fahr.) for a streaming motion of the protoplasm in the hairs. Place the specimen upon a block of ice, and note that the movement ceases. Warm again, etc.

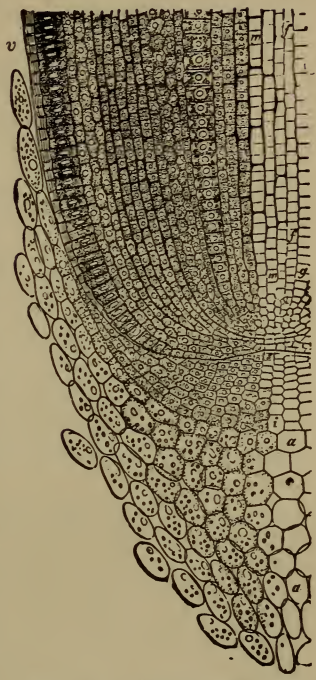


FIG. 4.—A little more than half of a longitudinal section of the tip of a young root of Indian Corn. The part above *s* is the body of the root, that below it is the root-cap; *v*, thick outer wall of the epidermis; *m*, young pith-cells; *f*, young wood-cells; *g*, a young vessel; *s*, *i*, inner younger part of root-cap; *a*, *a*, outer older part of root-cap.

(*d*) With similar specimens observe the effect of (1) iodine, which kills and stains the protoplasm; (2) alcohol, which kills and coagulates it; (3) glycerine, which withdraws water from it, and so collapses it.

(*e*) Mount carefully in pure water a piece (2 to 4 centimetres) of one of the young "silks" of Indian corn. The movement is well seen in the long cells. Repeat the foregoing experiments.

(*f*) The following may be taken also, viz.: the stamen-hairs of Spiderwort, the epidermis of Live-for-ever leaf, fresh specimens of the Stoneworts (Chara and Nitella), Eel-grass, etc.

(*g*) For very careful study the following method of preparation should be followed : Place a fresh root-tip of Indian corn, onion, or hyacinth in a 1-per-cent aqueous solution of chromic acid for twenty or twenty-four hours ; thoroughly wash it for some hours in running water ; place it successively in 20-, 30-, 50-, 75-, 95-per-cent, and absolute alcohol, allowing it to remain in each for a few hours ; then transfer it to turpentine, a few hours later to a warm mixture of turpentine and paraffin, and still later (3 to 4 hours) to melted paraffin, where it must be kept for 24 to 48 hours at a temperature of about 60° C. When cooled the specimen will be firmly imbedded in the paraffin, and may be cut into very thin sections on any microtome. The sections may then be attached to a glass slip by a film of collodion, the paraffin removed by heat, turpentine, and alcohol, and afterwards stained by hæmatoxylon, carmine, or safranin. The specimens must now be again dehydrated by the application of 50-, 75-, 95-per-cent, and absolute alcohol, the alcohol washed off by turpentine, Canada balsam added, and the cover-glass put in place. When dry and hard the specimen is ready for study under a very high power (1000 diameters or more) of the microscope.

7. The Plant-cell.—In all common plants the protoplasm is usually found in minute masses (consisting of the cytoplasm, nucleus, chromatophores, and centrospheres) of definite shapes, each one enclosed in a little box (Fig. 1, *w*). The substance of these boxes was made by the protoplasm, somewhat as the snail makes its shell. Each mass of protoplasm with its box is called a Plant-cell, and the sides of the box are called the walls of the cell, or the cell-wall.

8. The young cell-wall consists of cellulose, which is composed of carbon, hydrogen, and oxygen ($C_6H_{10}O_5$). At first it is very thin, but as the protoplasm grows older it thickens its wall by continually adding new material to it, so that at last it may be many times as thick as at the beginning. Moreover as it grows older other substances are deposited or developed in the wall, so that it is no longer pure cellulose. Thus the walls of cork and epidermal cells contain cutin (suberin), those of wood-cells lignin, while

in some cases, e.g. diatoms and the superficial cells of joint-rushes and grasses, silica or other mineral matters are deposited. On the other hand the cellulose may degenerate into mucilage, e.g. gum arabic, cherry gum, flaxseed, many water-plants, etc.

9. The cell-wall may be thickened uniformly, or, as more frequently happens, some portions may be much more thickened than others. When it is uniform the wall shows no markings of any kind, but when otherwise it shows dots, pits, rings, spirals, reticulations, etc. etc. (Fig. 5). This thickening gives strength to the cell-wall, and

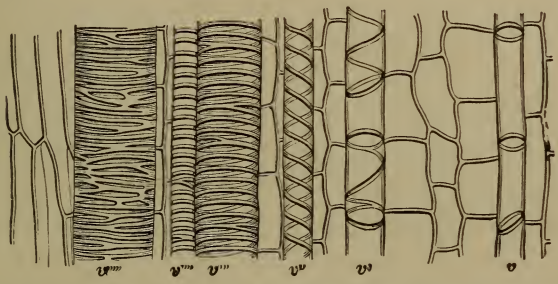


FIG. 5.—Longitudinal section of a portion of the stem of Garden Balsam. *v*, ringed vessel; *v'*, a vessel with thickenings which are partly spiral and partly ringed; *v''*, *v'''*, *v''''*, several varieties of spiral vessels; *v'''''*, a reticulated vessel.

serves either to protect the protoplasm, as in many spores and pollen-grains, or to help in building up the framework of the plant.

10. Careful examination of the cell-walls, even when much thickened, shows that the protoplasm of contiguous cells is not completely separated. Delicate fibrils of protoplasm extend through minute openings in the walls, connecting the greater part of the cells throughout the plant.

11. Cells in plants are of various sizes and shapes. The largest (with a few exceptions) are scarcely visible to the naked eye, while the smallest tax the highest powers of the

best microscopes. Cells which exist by themselves, as in many microscopic water plants, are more or less spherical; so, too, are many spores and pollen-cells, and the cells of many ripe fruits, where, in the process of ripening, the cells have separated from each other. Ordinarily, however, the cells are of irregular shapes, on account of their mutual pressure. Occasionally they are cubical, rarely they are regular twelve-sided figures (dodecahedra), but more commonly they are irregular polyhedra.

12. In some of the lower aquatic plants cells occur which for a time have no cell-wall (e.g. zoöspores), but after a short period of activity they come to rest and cover themselves with a wall of cellulose. In some lower plants also the cells contain more than one nucleus (e.g. in Water-net, Water-flannel, etc.). In most plants, however, the walled cells, each containing a single nucleus, are the units of which the plant is composed, and in the study of different plants, no matter how much they may differ in external appearance, we shall always find that they are made up of cells alike in all essential features. Thus the simple Green Slime of the rocks is composed of a single cell, the homologue of which is repeated millions of times in the giant oak of the forests.

Practical Studies.—(*a*) Mount a leaf of a moss for a good example of cells showing their walls. The sections of root-tips previously mentioned (p. 5) may be studied again with profit.

(*b*) For thickened cell-walls make sections of the shell of the hickory-nut or cocoanut.

(*c*) Make longitudinal and also cross sections of apple-twigs; some of the pith-cells show thickened walls marked by dots and pits.

(*d*) Make the following tests upon cell-walls: Apply sulphuric acid and iodine—the cellulose-walls will turn blue or violet, the cutin and lignin walls yellow or brown. To separate the latter apply aniline-water safranin, which stains the cutin-walls a yellowish and the lignin-walls a bluish color.

(*e*) Make longitudinal sections of a stem of Indian corn, so as to obtain very thin slices of some of the threads which run lengthwise through it. Cell-walls showing rings, spirals, and reticulations may be readily found (Fig. 5).

(*f*) Mount spores of the "black rust" of wheat or oats (by carefully scraping off one of the blackish spots on the stem or leaves) for examples of cell-walls thickened for protection.

(*g*) Mount pollen-grains of mallows or squashes for thickened wall which has developed projections externally.

(*h*) Make longitudinal sections of the fibrovascular bundles of squash-stems for examples of sieve-vessels showing the continuity of the protoplasm through the cell-walls.

(*i*) For large cells examine the parts (leaves and stems) of water-plants. In the Water-net (Hydrodictyon) they may be seen with the naked eye.

(*j*) For very small cells mount a minute drop of putrid water and examine with the highest power of the microscope available. Myriads of minute cells, each a single plant, will be seen darting hither and thither in the water. These are the Bacteria, to be more fully noticed in Chapter VII. A tumbler in which leaves and twigs have been allowed to begin to decay will furnish good material.

(*k*) For Green Slime scrape off a little of the green, slimy growth to be found on damp walls, rocks, etc. Under a high power many little green balls of protoplasm may be observed. Each has a cell-wall.

13. How New Cells are Formed.—Most plant-cells in some stage of their growth are capable of producing new cells. This power is mostly confined to their early thin-walled state, new cells being rarely formed after the walls have attained any considerable thickness. There are two principal methods, viz., (1) by the Division of cells, (2) by the Union of cells.

14. In some cases of Division the cell simply constricts its sides so as to pinch itself into two parts. In other cases the protoplasm first divides itself through the middle, and the two halves then help to form a partition-wall of cellulose between them. Both of these modes of division are known as Fission.

15. In other cases of Division the protoplasm divides itself into two, four, or many parts, which then become spherical in shape. Each part then covers itself with a cell-wall of its own; and the old cell-wall of the original cell, not being of further use, soon decays or breaks away. This kind of Division is known as Internal Cell-formation.

16. In the Division of cells the nucleus divides first, after which the cytoplasm separates into two parts. The nucleus usually undergoes a number of curious changes during its division, as follows: (*a*) the centrospheres separate and move to opposite sides of the nucleus (Fig. 6, *B*);

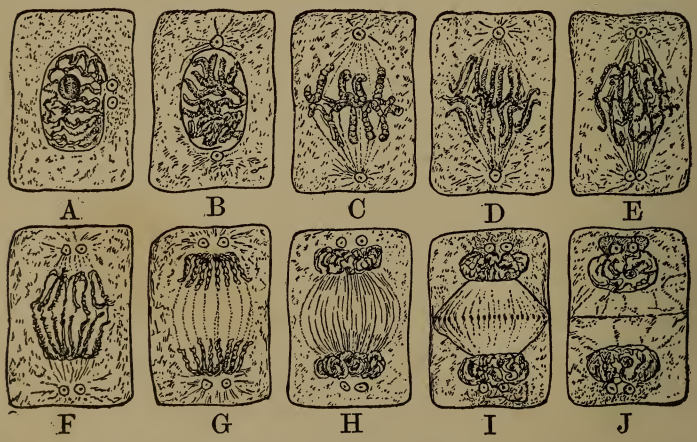


FIG. 6.—Indirect division of a cell. *A*, before any changes have taken place; *B*, the formation of chromosomes; *C*, nuclear disk, and kinoplasmic spindle; *D*, splitting of the chromosomes; *E*, *F*, separation of the daughter fibrils; *G*, polar disks; *H*, *I*, *J*, new nuclei, and division of the cytoplasm. × 600. (From Strasburger.)

(*b*) the fibrillar network breaks up into short, V-shaped fibrils (the *chromosomes*) which move toward the equator of the nucleus, forming the nuclear disk (Fig. 6, *C*); (*c*) the kinoplasm becomes arranged in lines extending from the nuclear disk to the centrospheres, constituting the kino-

plasmic spindle; (*d*) the chromosomes split longitudinally, and the daughter-fibrils move along the kinoplasmic spindle to the centrospheres (which have divided) where they form the polar disks (Fig. 6, *G*); (*e*) the polar disks gradually assume the form of tangled fibres of the new nuclei. When these changes are nearly completed the cytoplasm divides in a plane between the two new nuclei, and in this plane a wall of cellulose is secreted. The foregoing is the indirect or mitotic cell-division, and the nuclear changes constitute *karyokinesis*. Some cells undergo direct or amitotic division, the nuclei separating at once into two parts without the intervention of the karyokinetic stages.

17. Cell-division always results in an increase in the number of cells, and is the usual process by which plants are increased in size, and in the number of their cells. Growth may be very rapid, even where the cells simply divide successively into two. Thus a single cell may give rise in its first division to two cells, next to four, then eight, then sixteen, thirty-two, sixty-four, etc. etc. By the twentieth division the cells would exceed a million in number.

18. The process of cell-formation by Union is exactly opposite to that by Division. Two cells which were separate unite their protoplasm into one mass, which then forms a cell-wall around itself. Thus instead of doubling the number of cells at every step, there is here an actual decrease, and every time the process occurs the result is but half as many cells as before (Fig. 73, *A*, *B*, *C*).

Practical Studies.—(*a*) Carefully scrape off (after moistening with a drop of alcohol) a little of the white, mouldy growth on lilac-leaves, known as Lilac Mildew; mount it in water, adding a very little potassic hydrate. Some of the threads will show the formation of new

cells (spores in this case) by fission. Other kinds of mildews, as for example that on grass-leaves or that common on the leaves of cherry-sprouts, furnish equally good examples. (See Fig. 97, p. 175.)

(*b*) Strip off carefully a bit of the epidermis of a young Live-for-ever leaf, and mount it in water. By careful examination some of the cells may be observed with very thin partition-walls formed across them. The new walls can be distinguished from the older ones by their thinness.

(*c*) Mount a very small drop of yeast in water and observe in the yeast-plants that modification of fission which is called budding. Each yeast-plant is a minute oval cell; it first pushes out a little protrusion which becomes larger and larger, finally equalling the first. In the mean time a partition forms between the two, which then separate from one another. (Fig. 7, *a* and *b*.)

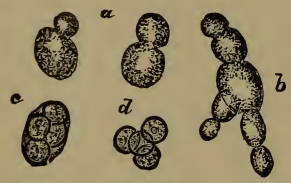


FIG. 7.—Yeast-plants reproducing by Division: *a* and *b* by budding; *c* and *d* by internal cell-division. Highly magnified.

(*d*) Grow some yeast for a few days under a bell-jar on a moist slab of plaster, a cut potato or carrot, or even a bit of moist brown paper. Upon examining such yeast it will be found that some of the cells contain several little new cells, formed by internal cell-division. (Fig. 7, *c* and *d*.)

(*e*) Make very thin cross-sections of young flower-buds so as to cut through the stamens. If the specimen is of the proper age, certain cells may be seen to have divided internally into four parts, each of which subsequently becomes a pollen grain having a thick cell-wall of its own.

(*f*) By carefully staining very thin sections of the preceding (*e*) several of the successive stages of cell-division may sometimes be seen by the aid of high powers of the microscope. They may be seen also in the stamen-hairs of the Spiderwort, and the embryo-sac of Fritillaria, but for the successful study of karyokinesis the protoplasm must first be suddenly killed in chromic acid, absolute alcohol, or some other substance, and then very carefully sectioned and stained. (See *g*, page 6.)

(*g*) Good examples of cell-formation by Union may be studied in any of the common Pond Scums (Spirogyra) to be found in every pond in summer and autumn.

19. Chromatophores.—Three varieties of chromatophores occur in plants, as follows:

(1) Masses of protoplasmic matter, usually small and rounded, which are stained green by chlorophyll ; these are called *chloroplasts*, or in higher plants chlorophyll-granules (Fig. 8). The chlorophyll is a stain made by the cell itself, the chloroplast being only the portion of the protoplasm stained by it. The two may be separated by alcohol, which dissolves out the chlorophyll, leaving the chloroplast as a colorless mass. Chloroplasts occur in the cytoplasm of cells in all green parts of plants, and increase in numbers by fission. In some lower plants they are star-shaped or bandlike, but in all higher plants they are small, rounded bodies. They develop chlorophyll in the light only, and in prolonged darkness even that which is already formed disappears. Parasites and saprophytes generally produce no chlorophyll.

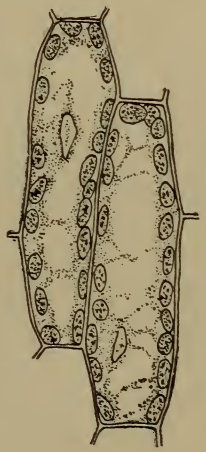


FIG. 8.—Two cells of a Moss-leaf (Funaria), magnified 300 diameters, showing chloroplasts. (From Strasburger.)

(2) In many flowers and fruits the chromatophores are needle-shaped or angular, and of a yellow or red color. These are known as *chromoplasts*, and are supposed to be related to chloroplasts, but they are stained with xanthophyll instead of chlorophyll. They occur, also, in the roots of some plants, as for example the carrot, where the staining matter is carotin.

(3) In parts of plants not exposed to the light the chromatophores are colorless, and bear the name of *leucoplasts*. On exposure to the light they become green by the formation of chlorophyll, thus developing into chloroplasts.

Practical Studies.—(*a*) Mount a leaf of a moss and examine for chloroplasts.

(*b*) Soak a few moss-leaves in alcohol for twenty-four hours, and note the decoloration of the chloroplasts. Note the green color given to the alcohol.

(*c*) Carefully study the cells of several fungi, as Lilac Mildew (parasites), toadstools, puffballs, etc. (saprophytes), and note the absence of chlorophyll.

(*d*) Examine the yellow cells of the petals of the Nasturtium (Tropæolum), and of the root of the carrot for chromoplasts. Examine also the red cells of a ripe tomato.

(*e*) Make sections of a potato-stem grown in darkness. Compare this with a stem of the same plant grown in light.

(*f*) Make sections of blanched celery. Compare with unblanched.

(*g*) Dissolve out the chlorophyll (by alcohol) from a specimen (any of the foregoing) and then treat with iodine. Note the brown color given to the bleached chloroplasts, showing them to be protoplasm.

20. Starch.—Many cells of common plants contain little grains of starch (Fig. 9). In some cases, as in the potato-tuber, the cells are only partially filled, but in other cases, as in rice, wheat, Indian corn, etc., the starch is packed so closely in the cells as to leave very little unfilled space.

21. The starch of every plant is originally manufactured in chloroplasts, that is, in masses of stained protoplasm. It moreover forms only in the light, so that plants which have no chlorophyll, or which grow in darkness, do not make starch. After starch has once been formed it may be transformed to sugar or some other soluble substance, and diffused to distant parts of the plant, where by the activity of the leucoplasts it may be deposited again, this time independently of the presence or absence of light (Fig. 10).

22. Chemically, starch is much like sugar and cellulose, and like them it is composed of carbon, hydrogen, and oxygen ($C_6H_{10}O_5$). It contains water in its organization, which may be driven off by heat, or by the application of reagents, when it loses its structure.

23. Starch is a plant-food. It is produced by the green protoplasm for the nourishment of the plant. As it forms only in light, during the day it accumulates, but at night

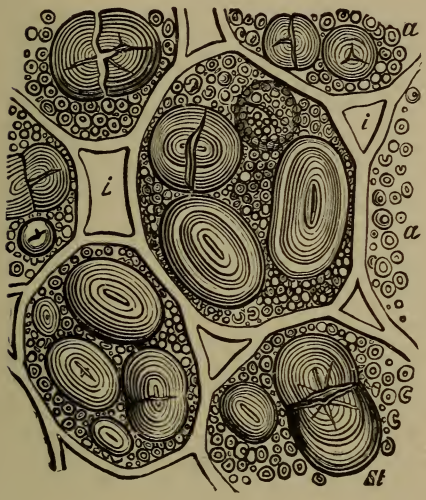


FIG. 9.

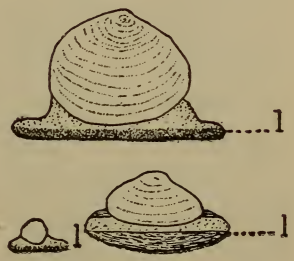


FIG. 10.

FIG. 9.—A few cells of the seed of a Pea, showing large starch-grains (*St*) and the little granules of aleurone (*a*). At *i*, *i*, are shown intercellular spaces. Magnified 800 times.

FIG. 10.—Leucoplasts (*l*) and young starch-grains of an orchid (Phajus). Magnified 540 diameters. (From Strasburger.)

by the continued activity of the plant it is greatly diminished. Whenever there is more made than the plant requires, the surplus is stored by the leucoplasts in certain cells for future use.

Practical Studies.—(*a*) Scrape off a little of the substance of the cut surface of a potato-tuber. Mount in water and examine under the microscope, using the $\frac{1}{6}$ objective. Note the ovate starch-grains, which are concentrically striated. Now add a small drop of iodine and note the blue coloration, which becomes purple or purple-black if much iodine is used.

(*b*) Make an extremely thin slice of the potato-tuber and treat as before, so as to observe starch-grains in the cells. By staining such

a section with carmine the protoplasm in the starch-bearing cells may be made evident.

FIG. 11.—Two plants of Pond Scum (Spirogyra), showing spiral chloroplasts, each with aggregations of starch. At *a* and *b* the cells are beginning to branch preparatory to uniting. Magnified 500 times.

(*c*) Study the starch of wheat, rice, Indian corn, oats, etc.

(*d*) Mount carefully a few threads of Pond Scum (Spirogyra) which have been for some hours in the sunlight. Note the aggregations of minute starch-grains in the spiral chloroplasts (Fig. 11). Now add iodine and observe the coloration of starch-grains.

(*e*) Make thin sections of leaves which have been in the light for some hours, and observe minute starch-grains in the chlorophyll-bodies. Use iodine as above.

(*f*) Make longitudinal sections of ripened apple-twigs and note the starch stored in certain cells of the pith for use when growth is resumed.

24. Aleurone.—In mature seeds there are commonly to be found small rounded granules of albuminous matter to which the name of Aleurone has been given (Fig. 9). It is, in part at least, the protein matter of the older botanists. It is also identical with what has been called the gluten of the grains of wheat, rye, oats, etc.

25. Aleurone is poorly understood, but it appears to be a dry resting state of protoplasm. Some, if not all, of it may become active again upon the access of water and the proper temperature. Possibly some of it serves as food for protoplasm in the germination of seeds.

Practical Studies.—(*a*) Mount in alcohol or glycerine a thin slice of a ripe pea. Note the small granules (along with large starch-

grains) in the cells (Fig. 9). Apply iodine, which will stain the aleurone yellow or brownish yellow.

(*b*) Make a similar study of the aleurone of the bean.

(*c*) Make sections of the foregoing and mount in water to observe the solution of the aleurone-grains. The process may be hastened by adding a very little potassic hydrate.

(*d*) Make thin cross-sections of a wheat-kernel and study the gluten (aleurone) cells of the inner bran. Add iodine.

(*e*) Make a similar study of the bran of rye, oats, and Indian corn.

26. Crystals.—Some cells of certain plants contain crystals (Fig. 12). These are of various shapes, one of the most common forms being needle-shaped, while others are cubical, prismatic, etc. They are frequently clustered into little masses.

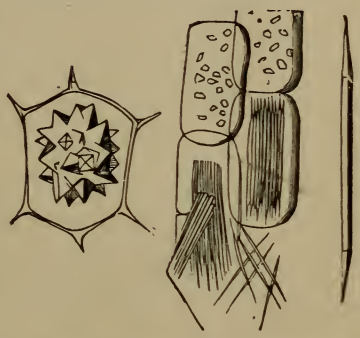


FIG. 12.—Crystals of calcium oxalate. The right-hand portion of the figure shows two cells of Rhubarb, with their contained crystals, and one enlarged. On the left is a crystal from the beet. Much magnified.

27. Crystals are for the most part composed of calcium oxalate. That is, they are a combination of lime and oxalic acid. A few have a different chemical composition—as the calcium carbonate crystals found in nettles, hops, hemp, etc., besides others of still less frequent occurrence.

28. Crystals appear to be the residues from chemical reactions which take place in the interior of plants, and they probably have no further use.

Practical Studies.—(*a*) Mount in water several thin longitudinal sections of the stem of the Spiderwort (Tradescantia) and note the bundles of needle-shaped crystals in enlarged, thin-walled cells. Many crystals will be found floating free in the water, having been separated in the preparation of the specimen.

(*b*) Similar sections of the stem of the Evening Primrose, Fuchsia,

Balsam or Touch-me-not (Impatiens), and Garden Rhubarb will also show needle-shaped crystals.

(*c*) Other crystal forms may be obtained from the beet, onion (the scales), Pigweed, or Lamb's-quarters (Chenopodium), etc.

29. The Cell-sap.—All parts of a living cell are saturated with water. It enters into the structure of the cell-wall; it makes up the greater part of the bulk of the protoplasm, and it fills the vacuoles. It holds in solution the food-materials absorbed from the air and soil, and the surplus soluble substances manufactured by the plant.

30. Among the many substances dissolved in the cell-sap the more important are Sugar and Inulin. Of the former there are two varieties, viz., sucrose, or cane-sugar ($C_{12}H_{22}O_{11}$), and glucose, or grape-sugar ($C_6H_{12}O_6$), which differ in their sweetness as well as in other properties.

31. Cane-sugar exists in great abundance in the cell-sap of sugar-cane, sugar-maple, sugar-beet, Indian corn, and in greater or less quantity in nearly all higher plants. Grape-sugar is found in many fruits, sometimes mixed with cane-sugar; thus in grapes, cherries, gooseberries, and figs it is the only sugar present, while in apricots, peaches, pine-apples, plums, and strawberries it is mixed with cane-sugar.

32. Inulin ($C_6H_{10}O_5$) is a soluble substance related to starch and sugar, which is found mainly in the cell-sap of certain Composites, as the sunflower, dahlia, elecampane (Inula), etc.

Practical Studies.—(*a*) Make a thin section of the stem of any herbaceous plant, as a Geranium; examine at once without a cover-glass, noting the wateriness. Lay the specimen aside for half an hour or so, and then note its shrinkage by loss of water.

(*b*) Mount a few plants of Pond Scum (Spirogyra) in a very little water. Examine under the high power of the microscope, and while doing this flow glycerine under the cover-glass. The glycerine im-

bibing water with great avidity withdraws the water of the cell-sap from the cells, causing them to collapse.

(*c*) The presence of sugar may be demonstrated in many cases by taste alone, as in the stems of cane and Indian corn.

(*d*) Cane-sugar when abundant may be crystallized out (in small stellate crystals) from cell-sap by the use of strong alcohol or glycerine.

(*e*) Make thin slices of the root of the sunflower or dahlia, and soak for some days in alcohol: the inulin will appear in the shape of sphere-crystals of greater or less size according as the crystallization has been slower or more rapid.

(*f*) The presence of acids in the cell-sap of many plants may be shown by placing a moist cut surface in contact with blue litmus-paper. The latter will be distinctly reddened. On the other hand the presence of alkalies may be shown by using red litmus paper, which is turned blue.

CHAPTER II.

THE TISSUES OF PLANTS.

33. Some plant-cells live alone, and are not connected with any others; some which are at first separate afterward unite into a cell-colony. In most cases, however, the cells are united to each other from the beginning of their existence into what are called **tissues.**

34. As understood in this book a plant-tissue is an assemblage of similar cells which have been united with each other from their beginning. The cells in a tissue may be arranged in rows, surfaces, or masses: in the first the growth has been by the fission of cells in one plane only, in the second from fission in two planes, and in the third from fission in three planes.

35. Rudimentary Tissue (*Meristem*).—When the cells are young their walls are thin and alike, but as they grow older they change in shape, in the thickness and markings of their walls, as well as in their contents. Every cell has its young state, its period of active growth, and finally its condition of maturity. Tissues composed of immature cells are thus much alike, but as they grow older they are differentiated more and more. We may thus distinguish between *rudimentary* and *permanent* tissues, and since the latter constitute the bulk of the mature

parts of plants, they are of greatest importance in the present study.

Practical Studies.—(*a*) Make very thin longitudinal sections of a root of Indian corn. The large strong roots which first start out from the germinating grain, and the youngest states of those which appear just above the ground, upon the large plants, are best for these specimens. Stain some of the sections with carmine.

(*b*) Make very thin longitudiual sections of the opening buds of the lilac or elder.

(*c*) Make similar sections of the tips of the young shoots of asparagus. Stain with carmine.

(*d*) Make cross and longitudinal sections of the youngest states of the stems of the pumpkin, squash, and asparagus, and compare with similar sections of older parts.

36. In the lower plants the cells are all alike, or so nearly so that they constitute but one kind of tissue. As we ascend from these simple forms the cells begin to show differences, some being especially developed for one purpose, and some for another; and these differences become more numerous and more sharply marked as we approach the higher plants. This at last gives us many kinds of tissues, which may be distinguished from each other by characters of greater or less importance. However, they may all be brought within seven general kinds, each kind showing many varieties.

37. Soft Tissue (*Parenchyma*).—This is the most abundant tissue in the vegetable kingdom; it is at once the most important and the most variable. It is composed of cells whose walls are thin, colorless, or nearly so, and transparent; in outline they may be rounded, cubical, polyhedral, prismatic, cylindrical, tabular, stellate, and of many other forms. When the cells are bounded by plane surfaces, generally, but not always, the end planes lie at right angles to the longer axis of the cells.

38. This tissue is the least diffentiated of all the tissues, and often differs but little from Rudimentary Tissue (*Meristem*). It makes up the whole of the substance of many of the lower plants, while in the higher it composes the essential portions of the assimilative (green), vegetative (growing), and reproductive parts.

Practical Studies.—(*a*) Make very thin cross and longitudinal sections of a green stem of Indian corn. After excluding the woody bundles, the whole of the central part of the stem is soft tissue.

(*b*) Make similar sections of the central part of the stem of the cultivated geranium.

(*c*) Make a very thin cross-section of an apple-leaf: the green cells are of soft tissue.

(*d*) Mount a whole moss-leaf: it is entirely composed of soft tissue, although in its rudimentary midrib the cells have elongated, as if foreshadowing the higher tissues.

(*e*) Mount several threads of Pond Scum: the whole plant is here composed of soft tissue.

39. Thick-angled Tissue (*Collenchyma*).—The cells of this tissue are elongated, usually prismatic, and their transverse walls are most frequently horizontal, rarely inclined. The walls are greatly thickened along their longitudinal angles, while the remaining parts are thin (Fig. 13). Wet specimens show by transmitted light a characteristic bluish-white lustre, which is best seen in cross-sections. The cells contain chlorophyll, and for some time retain the power of fission. Without question this

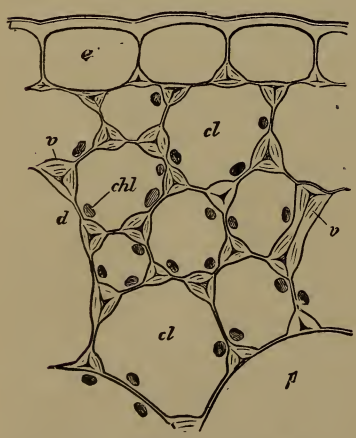


FIG. 13.—Cross-section of thick-angled tissue (*cl*) of Begonia petiole, showing the thickened angles. *e*, epidermis; *chl*, chloroplasts. Magnified 550 times.

tissue is closely related to soft tissue, of which it is considered by some botanists to be a variation.

40. Thick-angled tissue is found beneath the epidermis of most flowering plants (and some ferns), usually as a mass of considerable thickness, and is doubtless developed from soft tissue for the purpose of giving support and strength to the epidermis.

Practical Studies.—(*a*) Examine a leaf-stalk of the squash or pumpkin, and note the whitish bands, one or two millimetres wide, which extend from end to end just beneath the epidermis. These are bands of thick-angled tissue. They may be readily torn out, when the stalk will be found to have lost much of its strength.

(*b*) Make a very thin cross-section of the preceding leaf-stalk, and note the appearance of the thick-angled tissue first under a low power and then under a higher. The sections must be made exactly at right angles to the axis of the bands of tissue in order to show well.

(*c*) Make a number of longitudinal sections of the same leaf-stalk, in each case cutting through a band of the thick-angled tissue. Some of these will show the thickened angles, although there is always some difficulty in making them out in this section.

(*d*) The stems of squash, pumpkin, pigweed, or lamb's-quarters (Chenopodium), beet, and many other plants may be taken up next, and their thick-angled tissue studied in cross and longitudinal sections.

41. Stony Tissue (*Sclerenchyma*).—In many plants the hard parts are composed of cells whose walls are thickened, often to a very considerable extent (Fig. 14). The cells are usually short, but in some cases they are greatly elongated; they are sometimes regular in outline, but more frequently they are extremely irregular. They do not contain chlorophyll, but in some cases (e.g., in the pith of apple-twigs) they contain starch.

Practical Studies.—(*a*) Break the shell of a hickory-nut, and after smoothing the broken surface cut off a very small thin slice; mount in water and a little potassic hydrate: the cell-walls are so greatly thickened as to almost obliterate the cell-cavity.

(*b*) Study similarly the stony tissue of the cocoanut, walnut, peach, cherry, etc.

(*c*) Make cross-sections of the seed-coat of the apple, squash, melon, wild cucumber (Echinocystis), etc. It is instructive to make sections, also, parallel to the surface of the seeds.

(*d*) Make longitudinal sections of the pith of apple-twigs and note that some of the cells have thickened walls. These are very hard, and are to be regarded as a form of stony tissue. They contain starch.

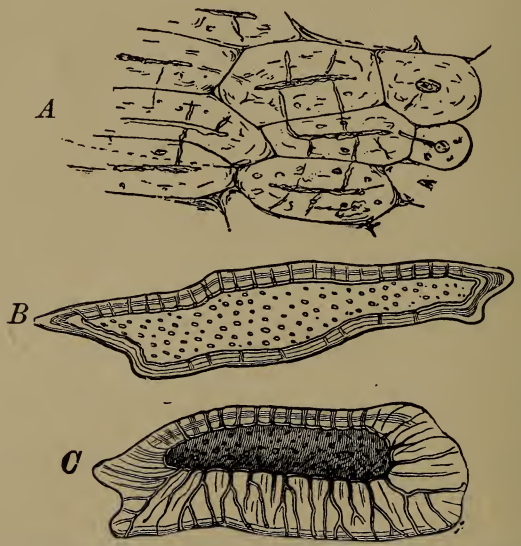


FIG. 14.—Stony tissue. *A*, from shell of Hickory-nut; *B* and *C*, from underground stem of the common Brake (Pteris). Magnified 400 to 500 times.

42. Fibrous Tissue. — This is composed of elongated, thick-walled, and generally fusiform fibres (Fig. 15), whose walls are usually marked with simple or sometimes bordered pits. These fibres in cross-section are rarely square or round, but most generally three- to many-sided. They are found in, or in connection with, the woody bundles of ferns and flowering plants, and give strength and hardness to their stems and leaves.

43. Two varieties of fibrous tissue may be distinguished, viz., (1) Bast (Fig. 15, *B*), and (2) Wood (Fig. 15, *A*).

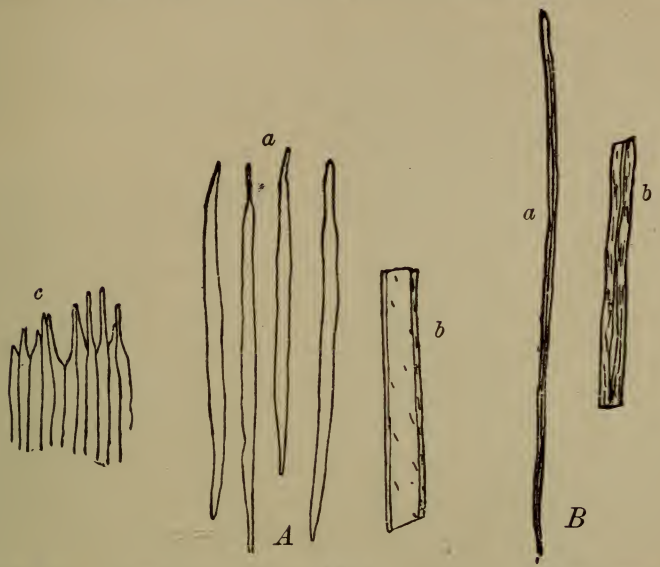


FIG. 15.—*A*, wood-fibres of Silver Maple isolated by Schulze's maceration; *B*, bast-fibres; *b*, *b*, portions of fibres more highly magnified.

The fibres of the former are usually thicker-walled, more flexible, and of greater length than those of the latter. In both forms the fibres are sometimes observed to be partitioned.

Practical Studies.—(*a*) Split a young maple-twig, then with a very sharp knife start a thin longitudinal radial section, completing it by tearing it off. Mount in water. The torn end will show good wood-fibres.

(*b*) Make a very thin cross-section of the wood of the same twig. Note the angular shape of the wood-fibres in this section.

(*c*) Make a cross-section of the bark of the same twig and note the white bundles of bast-fibres, each fibre having greatly thickened walls and a very narrow cell-cavity.

(*d*) Now make several longitudinal sections of the same twig so as to cut through one of the bundles of bast-fibres. Note the great length of the bast-fibres.

(*e*) Make cross-sections of the wood of various trees, as oak, hick-

ory, elm, ash, poplar, willow, and basswood, and note the differences in the amount and compactness of their fibrous tissue.

(*f*) To isolate the wood-fibres, make a number of sections as in (*a*) above, then heat for a minute or less in nitric acid and potassium chlorate. The fibres may now be separated under a dissecting microscope, or the specimens may be transferred to a glass slide and dissected by tapping gently upon the centre of the cover-glass. This is known as Schulze's maceration.

44. Milk-tissue (*Laticiferous Tissue*).—In many families of flowering plants tissues are found which contain a milky or colored fluid—the latex. For the sake of simplicity two general forms may be distinguished: (1) that *composed of simple or branching tubes* (Fig. 16), which are scattered through the other tissues. As found in the Spurge family, they are somewhat simply branched and have very thick walls (Fig. 16, *B*); in other plants they are thin-walled and are sometimes inclined to anastomose. They extend through the other tissues of the plant, and have a growth of their own, branching and elongating as if they were independent plants. They contain protoplasm, and have many nuclei.

45. (2) The other form is that composed of *reticulately anastomosing vessels.* Here the tissue is the result of the fusion of great numbers of short cells. The walls are thin and often irregular in outline. In chicory, lettuce, etc., this form of milk-tissue is very perfectly developed as a constituent part of the outer portion of the woody bundles (Fig 17, *A* and *B*).

46. The latex of different plants contains different substances; thus in many spurges (Euphorbiaceæ) and milkweeds (Asclepiadaceæ) it contains caoutchouc, which yields india-rubber; in poppies it contains opium; in some cases alkaloid poisons are present, while in still others, as the

"Cow-tree" of South America, the latex is nutritious, and is used by the natives as a wholesome drink.

FIG. 16.

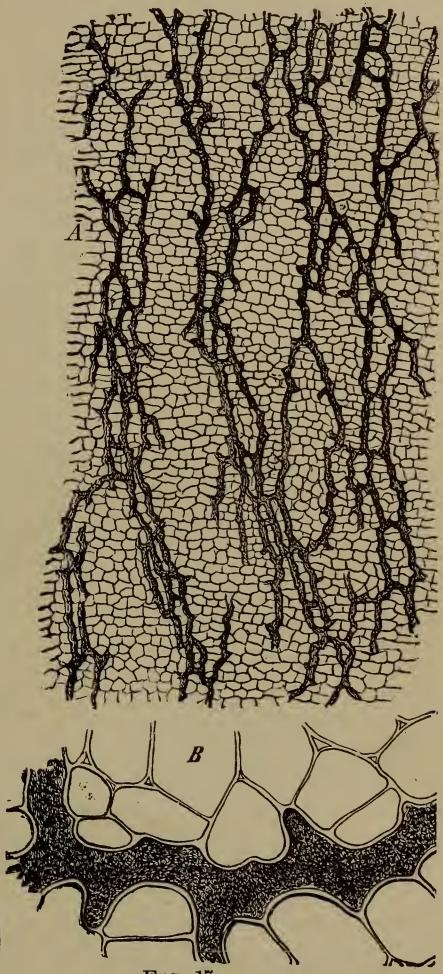


FIG. 17.

FIG. 16.—Milk-tubes from a Spurge (Euphorbia). *A*, moderately magnified; *B*, more highly magnified, and showing the bone-shaped starch-grains.

FIG. 17.—Milk-vessels of a Composite (Scorzonera). *A*, a transverse section of the root; *B*, the same more highly magnified.

Practical Studies.—In studying milk-tissue it is necessary first to

examine a drop of the milk (latex) under the microscope by transmitted light. When so examined it presents quite a different appearance from that by ordinary reflected light; thus white latex appears to be light granular brown.

(*a*) Make thin longitudinal sections of the stem of a Milkweed (Asclepias). By careful searching, tubes containing latex (appearing light granular brown) may be seen.

(*b*) Make a similar study of the stem of the large Spurge (Euphorbia) of the greenhouses. Its milk-tissue is thick-walled and easily made out.

(*c*) The more complex or reticulated forms of milk-tissue may be obtained from the stems of wild lettuce, garden-lettuce, poppy, and blood-root.

(*d*) Collect a quantity of latex of a Spurge or Milkweed in a watch-glass and slowly evaporate it: the residue will be found to consist of a sticky, elastic material resembling india-rubber.

47. Sieve-tissue.—As found in the flowering plants this tissue is for the most part made up of sieve-ducts and the so-called latticed cells. The former (the sieve-ducts) consist of soft, not lignified, colorless tubes, of rather wide diameter, having at long intervals horizontal or obliquely placed perforated septa. The lateral walls are also perforated in restricted areas, called sieve-disks, and through these perforations and those in the horizontal walls the protoplasmic contents of the contiguous cells freely unite (Fig. 18).

48. The tissue composed of these ducts is generally loose, and more or less intermingled with soft tissue; in some cases even single ducts run longitudinally through the substance of other tissues. In the form described above it is found only as one of the components of the outer or bark portion of the woody bundles of plants.

49. The so-called *latticed cells* are probably to be regarded as undeveloped sieve-ducts, and hence the tissue they form may be included under sieve-tissue. Latticed cells are thin-walled and elongated; they differ from true

sieve-ducts principally in being of less diameter, and in having the markings but not the perforations of sieve-disks. Both of these differences are such as might be looked for in undeveloped sieve-tissue.

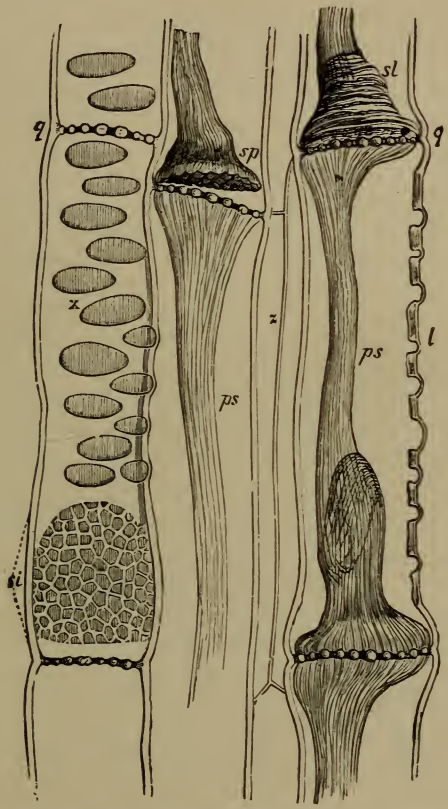


FIG. 18.—Longitudinal section through the sieve-tissue of Pumpkin-stem. *q*, *q*, section of transverse sieve-plates; *si*, lateral sieve-plate; *x*, thin places in wall: *l*, the same seen in section ; *ps*, protoplasmic contents contracted by the alcohol in which the specimens were soaked ; *sp*, protoplasm lifted off from the sieve-plate by contraction; *sl*, protoplasm still in contact with the sieve-plate. Magnified 550 times.

In the corresponding parts of the woody bundles of conifers and ferns a sieve-tissue is found which differs somewhat from that described above. In Conifers the sieve-disks, which are of irregular

outline, occur abundantly upon the oblique ends and radial faces of the broad tubes (Fig. 19). In the Horsetails (Equisetum) and Adder-tongues (Ophioglossum) they are prismatic, with numerous horizontal but not vertical sieve-disks; in Brakes (Pteris) and many other ferns they have pointed extremities, and are greatly elongated, bearing the sieve-disks upon their sides. In the larger Club-mosses the sieve-tubes are prismatic and of great length; in the smaller species there are tissue elements destitute of sieve-disks, but which are otherwise, including position in the stem, exactly like the sieve-ducts of the larger species.

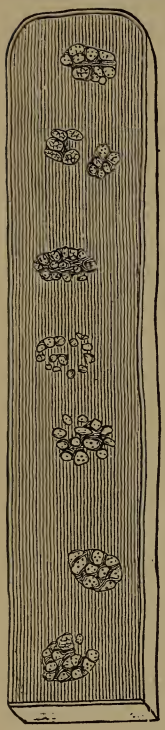


FIG. 19.—Sieve-tube of Big-tree of California (Sequoia gigantea), taken from the bark of an old stem. Magnified 375 times.

Practical Studies.—As sieve-tissue is always found in the woody bundles which run lengthwise through the higher plants, it is necessary first to make a cross-section of the stem to be studied in order to determine exactly the position of such bundles. It must be borne in mind that in most cases the sieve-tissue is confined to the outer side of the bundle, that is, to the side which faces the circumference of the stem. In the pumpkin, squash, melon, and related plants the bundles contain sieve-tissue on both outer and inner sides, that is on the side which faces the axis of the stem as well as on that which faces the circumference. This double nature of the bundles of these plants must be remembered in studying their sieve-tissue.

(*a*) Make a longitudinal radial section through one of the larger bundles of the stem of the pumpkin. The sieve-tissue will be distinguished by the thick-looking cross-partitions (this is mainly due to the adhesion of the protoplasm to the walls). By adding alcohol or glycerine the protoplasm of each cell may be contracted as in Fig. 18. In some cases where the partitions are oblique the perforations may be seen.

(*b*) Make very thin cross-sections of pumpkin-stem and examine carefully for sieve-plates. Where the section is made close to a plate it may be easily seen in such a specimen.

(*c*) Make similar studies of the stem of Indian corn.

50. Tracheary Tissue.—Under this head are to be grouped those vessels which, while differing considerably in the details, agree in having thickened walls, which are

generally perforated at the places where similar vessels touch each other. The thickening, and as a consequence the perforations, are of various kinds, but generally there is a tendency in the former to the production of spiral bands; this is more or less evident even when the bands form a network. The transverse partitions, which may be horizontal or oblique, are in some cases perforated with small openings, in others they are almost or entirely absorbed. The diameter of the vessels is usually considerably greater than that of the surrounding cells and elements of other tissues, and this alone in many cases may serve to distinguish them. When young they contain protoplasm, but as they become older this disappears, and they then contain air.

Tracheary tissue is found only in ferns and their relatives and the flowering plants. The principal varieties of vessels found in tracheary tissues are the following:

51. (1) *Spiral Vessels,* which are usually long, with fusiform extremities; their walls are thickened in a spiral

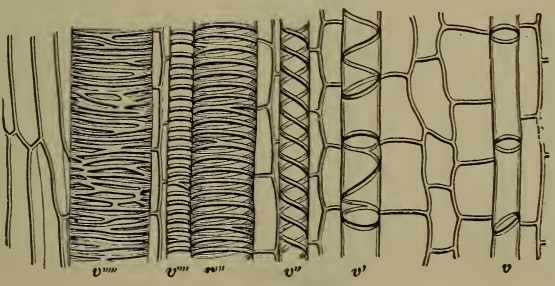
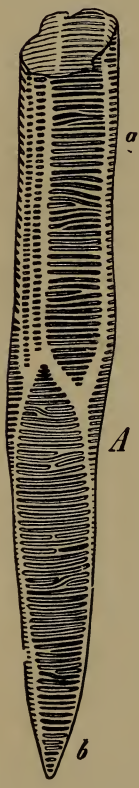


FIG. 20.—Longitudinal section of a portion of the stem of Garden Balsam (Impatiens). *v*, a ringed vessel; *v'*, a vessel with rings and short spirals; *v''*, a vessel with two spirals; *v'''* and *v''''*, vessels with branching spirals; *v'''''*, a vessel with irregular thickenings, forming the reticulated vessel. (From Duchartre.)

manner with one or more simple or branched bands or fibres (Fig. 20, *v''*, *v'''*, *v''''*). This form may be regarded

as the typical form of the vessels of tracheary tissue. *Ringed* and *reticulated* vessels are opposite modifications of the spiral form; the first are due to an under-development of the thickening in the young vessels, resulting in the production here and there of isolated rings (Fig. 20, *v*); reticulated vessels are due, on the contrary, to an over-development, which gives rise to a complex branching and anastomosing of the spirals (Fig. 20, *v*''''').



52. (2) *Scalariform Vessels.* — These are prismatic vessels whose walls are thickened in such a way as to form transverse ridges. They are wide in transverse diameter, and their extremities are fusiform or truncate (Fig. 21).

53. (3) *Pitted Vessels.*—The walls of these

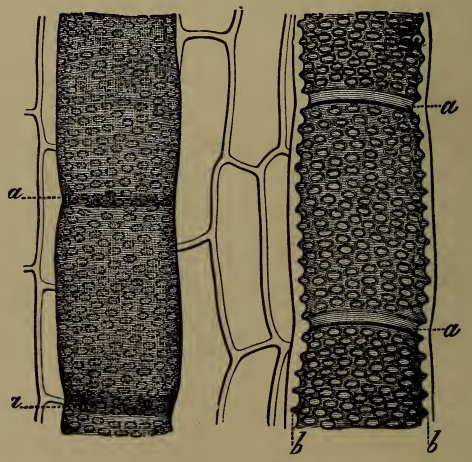


FIG. 21. FIG. 22.

FIG. 21.—Scalariform vessels of the common Brake (Pteris).

FIG. 22.—Pitted vessels of Dutchman's-pipe (Aristolochia sipho), from a longitudinal section of the stem; the vessel on the right is seen in section, that on the left from without. *a*, *a*, rings, which are remnants of the original transverse partitions; *b*, *b*, sections of the walls.

vessels are thickened in such a way as to give rise to pits and dots. The vessels are usually of wide diameter; in some forms they are crossed at frequent intervals by perforated horizontal or inclined septa (Fig. 22); in other forms they have fusiform extremities.

54. (4) *Tracheïds.*—These consist for the most part of single closed cells; otherwise they possess the characters of vessels. In one form (Fig. 23), as in the so-called wood-

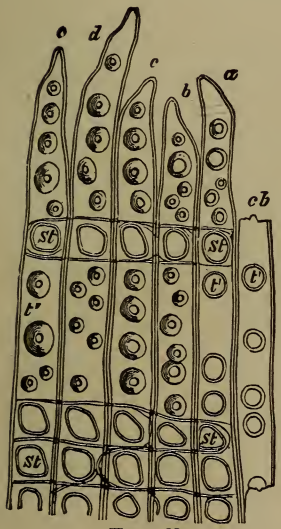


FIG. 23.

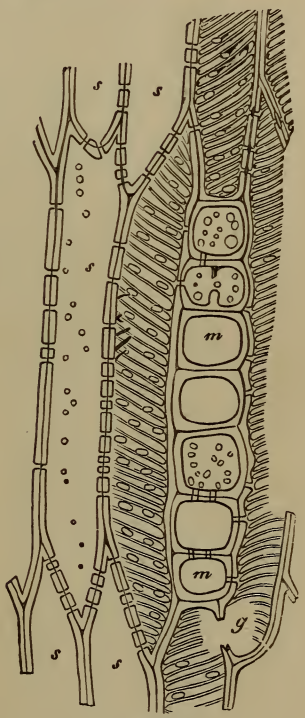


FIG. 24.

FIG. 23.—Ends of several tracheïds from the wood of a Pine, showing bordered pits. Magnified 325 times.

FIG. 24.—Tracheïds from the stem of Laburnum. *m*, *m*, cells of a medullary ray. At *g*, a partition is broken through. Magnified 375 times.

cells of Conifers, they are intermediate in structure between the pitted vessels and the fibres of the wood of other

flowering plants. Every gradation between these tracheïds and the other forms of tracheary tissue occur. In another form, as in the wood of many common trees and shrubs, the tracheïds are shorter than in the preceding, quite regular in their form, and with tapering extremities (Fig. 24). Their walls are but slightly thickened, and are marked with spirals and pits. When the wall between two contiguous cells breaks through or becomes absorbed, the close relation of such tracheïds to spiral vessels is readily seen.

Tracheïds may be regarded as composing a less differentiated form of tissue, related on the one hand to true tracheary tissue and on the other to fibrous tissue.

Practical Studies.—Here, as in the preceding, it is necessary, especially in herbaceous plants, to first determine by a cross-section the position of the woody bundles, as tracheary tissue is always confined to them.

(*a*) Make a thin longitudinal radial section through a bundle of the stem of the Garden Balsam or Touch-me-not (Impatiens). If successfully made it will show successively, passing *outward,* ringed, spiral, reticulated, and sometimes scalariform and pitted vessels, with gradations from one to the other, as in Fig. 20.

(*b*) Make a thin cross-section of the same and study carefully in connection with the foregoing.

(*c*) Make similar sections of the bundles of Indian corn. The large vessels which can be seen with the naked eye in cross-section are pitted.

(*d*) Study in like manner the tracheary tissue in the bundles of the pumpkin-stem. Here the large pitted vessels (which are very distinctly visible to the naked eye) have their walls thrown into numerous folds.

Note.—The large pores which are so distinctly visible in oak, chestnut, hickory, walnut, ash, and many other kinds of woods are pitted vessels like those of Indian corn and pumpkin.

(*e*) Excellent scalariform vessels may be obtained from the bundles of the leaf-stalks of ferns, or better still from the underground stem. In the latter the bundles lie adjacent to the thick dark bands of fibrous tissue.

(*f*) The tracheïds of Conifers (pines, spruces, etc.) make up very nearly the whole bulk of the wood of these trees. Make a longitudinal radial section of a pine-twig by the method employed in studying fibrous tissue (Schulze's maceration). Note that the tracheïds bear some resemblance to the wood-fibres of other wood. However, their large round bordered pits are characteristic.

(*g*) Make longitudinal tangential sections of the same twig. Note that the bordered pits are not seen (except in section) in specimens so made.

(*h*) Make cross-sections of the same twig and note that the tissue is homogeneous. Compare with a similar section of an oak-twig, and note the absence in the pine of the large pitted vessels which are so well shown in the oak.

(*i*) Make very thin longitudinal radial sections of the wood of hackberry. By careful examination tracheïds may be found resembling the wood-fibres, but marked with fine spirals.

(*j*) Similar tracheïds may be found intermingled with the wood-fibres of other trees, as the maple, box-elder, elm, etc.

CHAPTER III.

THE GROUPS OF TISSUES, OR TISSUE-SYSTEMS.

55. Primary Meristem.—The ends of young stems consist of rudimentary tissue (*meristem*), from which all the tissues formed in the plant are derived. As these stem-ends grow there is a continuous formation of additional meristem in the newer portions, while in the older portions the rudimentary tissue is changing into permanent tissues. There is thus always an advancing terminal mass of meristem, from which all the tissues of the stem are developed. This original rudimentary tissue is appropriately named the Primary Meristem.

56. In most plants below the flowering plants the primary meristem is produced by the continually repeated division of a single mother-cell situated at the apex of the growing organ. In the simplest forms this apical cell is the terminal one of a row of cells, as in many seaweeds and fungi. The apical cell, in such cases, keeps on growing in length, and at the same time horizontal partitions are forming in its basal portion. In this way long lines of cells may originate.

57. In the more complicated cases the segments cut off from the apical cell grow and subdivide in different planes, so as to give rise to masses of cells. The partitions which successively divide the apical cell are sometimes perpendic-

ular to its axis, but more frequently they are oblique to it. In most mosses, for example (Fig. 25), the apical cell is a triangular, convex-based pyramid, whose apex is its proximal portion. The successive segments are cut off from the apical cell by alternate partitions parallel to its sides, thus giving rise to three longitudinal rows of cells. Most ferns and their relatives have an apical cell not much different

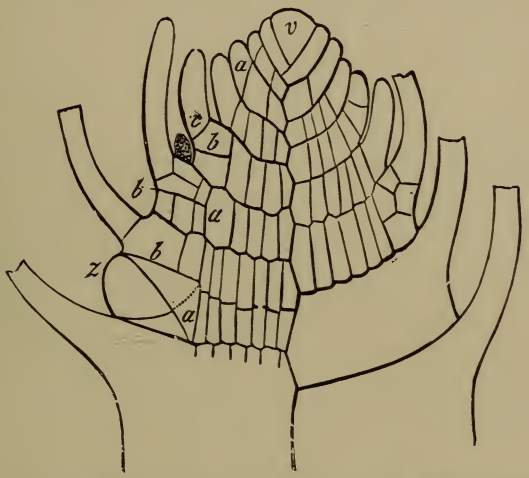


FIG. 25.—Longitudinal section of apex of stem of a Moss (Fontinalis antipyrerica). *v*, apical cell; *z*, apical cell of lateral leaf-forming shoot, arising below a leaf; *c*, first cell of leaf; *b*, *b*, *b*, cells forming cortex.

from that of the majority of mosses. In Horsetails, for example, it is an inverted triangular pyramid having a convex base. The segments (daughter-cells) are cut off by alternating partitions parallel to the plane sides of the pyramid, as in the mosses. In some mosses and ferns, however, the apical cell is wedge-shaped—i.e., with only two surfaces—and in such cases two instead of three rows of meristem-cells are formed.

58. In the flowering plants the primary meristem is usually developed from a group of cells, instead of from a

single one. This group of cells occupies approximately the same position in the organs of flowering plants as the apical cell does in the mosses and ferns; it is composed of cells which have the power of indefinite division and subdivision.

59. The apical cell and its actively growing daughter-cells in its immediate vicinity, or, in the case of the flowering plants, the apical group of cells with their daughter-cells, constitute the Growing Point or Vegetative Point of the organ. When this active portion is conical in shape it is also called the Vegetative Cone.

60. The Differentiation of Tissues into Systems.—It rarely happens that the tissues which compose the body of a plant are uniform. In the great majority of cases the cells of the primary meristem become differently modified, so as to give rise to several kinds of tissues. The outer cells of the plant become more or less modified into a boundary tissue, and the degree of modification has relation to its environment. Certain inner cells, or lines of cells, become modified into stony tissue, or some other supporting tissue (thick-angled or fibrous tissue), and here again there is a manifest relation to the environment of the plant.

61. Certain other inner cells, or rows of cells, become modified into tubes, affording a ready means for conduction, and appear to have a relation to the physical dissociation of the organs of the higher plants, in which only they occur. Thus, in physiological terms, there may be a boundary tissue, a supporting tissue, and a conducting tissue lying in the mass of less differentiated ground-tissue.

62. In different groups of plants the elementary tissues described in previous pages are aggregated in different ways, and are variously modified to form these bounding,

supporting, and conducting parts of the plant. Several tissues, or varieties of tissue, are regularly united or aggregated in particular ways in each plant, constituting what may be called Groups or Systems of Tissues. A Tissue-system may then be described as an aggregation of elementary tissues forming a definite portion of the internal structure of the plant.

63. From what has already been said, it is clear that systems of tissues do not exist in the lowest plants, and that they reach their fullest development only in the highest orders. It is evident also that these systems have no existence in the youngest parts of plants, but that they result from a subsequent development. Many systems of tissues might be enumerated and described; but here again, as with the elementary tissues, while there are many variations, there are also many gradations, having on the one hand a tendency to give us a long list of special forms, and on the other to reduce them to one, or at most to two or three.

64. The three systems proposed by Sachs are instructive, and will be followed here; they are: (1) the Epidermal System, composed mainly of the boundary cells and their appendages (hairs, scales, breathing-pores, etc.); (2) the Fundamental System, which includes the mass of unmodified or slightly modified tissues found in greater or less abundance in all plants (excepting the lowest); (3) the Fibro-vascular (or Skeletal) System, comprising those varying aggregations of tissues which make up the stringlike masses or woody bundles found in the organs of the higher plants.

65. In the primary meristem at the end of a shoot or root in the highest plants, several differentiations of the

rudimentary tissues may be distinguished before the permanent tissues have formed. Thus an outer layer, the *dermatogen*, whose cells divide only at right angles to the surface, eventually develops into the epidermis. In the centre is a mass of elongated cells, the *plerome*, from which the fibro-vascular system develops, while between plerome and dermatogen is the *periblem*, in which arise the various tissues of the fundamental system.

66. The Epidermal System of Tissues.—This is the simplest tissue-system, as it is the earliest to make its appearance, in passing from the lower forms to the higher. It is also (in general) the first to appear in the individual development of the plant. It is sometimes scarcely to be separated from the underlying mass, as in most lower plants; but in most higher plants it frequently attains some degree of complexity, and is sharply separated from the underlying ground-tissues.

67. In the simpler epidermal structures of the lower plants the cells are generally darker colored, smaller, and more closely approximated than they are in the subjacent mass; in some of the higher fungi a boundary tissue may be easily separated as a thickish sheet, but probably in such case a portion of the underlying mass is also removed. In many lower plants there is absolutely no differentiation of an epidermal portion.

68. The epidermal systems of ferns and flowering plants consist usually of three portions: (1) a layer of more or less modified parenchyma—the epidermis proper—bearing two other kinds of structures which develop from it, viz., (2) hairs, and (3) breathing-pores.

69. Epidermis.—The differentiation of parenchyma in the formation of epidermis, when carried to its utmost ex-

tent, involves three modifications of the cells, viz., change of form, thickening of the walls, and disappearance of the protoplasmic contents.

70. These may occur in varying degrees of intensity; they may all be slight, as in many aquatic plants and in the young roots of ordinary plants; or the cells may change their form, while there may be little thickening of their walls, as in other aquatic plants and some land-plants which live in damp and shady places; or, on the other hand, the change of form of the cells may be but little, while their walls may have greatly thickened, resulting in a disappearance of their protoplasm, as may be seen in parts of some land-plants which grow slowly and uniformly. When the differentiation of epidermis is considerable, it can usually be readily removed as a thin transparent sheet of colorless cells.

71. The change in the form of the epidermal cells is due to the mode of growth of the organ of which they form a part; the lateral and longitudinal growth of an organ causes a corresponding extension and consequent flattening of the cells; if the growth has been mainly in one direction, as in the leaves of grasses, or if the growth in two directions has been regular and uniform, the cells are quite regular in outline; where, however, the growth is not uniform the cells become irregular, often extremely so (Fig. 29, page 44).

72. The thickening of the walls is greatest in those plants and parts of plants which are most exposed to the drying effects of the atmosphere. It consists of a thickening of the outer walls, and frequently of the lateral ones also.

73. The outer portion of the thickened walls sometimes separates as a continuous pellicle, the so-called cuticle,

which extends uninterruptedly over the cells, and may be readily distinguished from the other portions of the outer epidermal walls. It is insoluble in concentrated sulphuric acid, but may be dissolved in boiling caustic potash. Treated with iodine it turns a yellow or yellowish-brown color. A waxy or resinous matter is frequently developed upon the surface of the cuticle, constituting what is called the *bloom* of some leaves and fruits.

74. The protoplasm of the epidermal cells generally disappears in those cases where there is much thickening of the walls; it is always present in young plants and parts of plants; it is also frequently present in older portions, which are not so much exposed to the drying action of the atmosphere, as in roots, and the leaves and shoots of aquatic plants and of those growing in humid places. In few cases, however, are granular protoplasmic bodies (e.g., chloroplasts) present in epidermal cells.

75. While the epidermis always consists at first of but one layer of cells, it may become split into two or more layers by subsequent divisions parallel to its surface, as in the Oleander and Cactus.

76. The Hairs of the epidermis originate mostly from the growth of single epidermal cells, and on their first appearance consist of slightly enlarged and protruding cells (Fig. 26, *e, f, c*). These may elongate and form single-celled hairs, which may be simple or variously branched. The most important of these hairs are those which clothe so abundantly the young roots of most of the higher plants, and to which the name of Root-hairs has been applied (Fig. 27). These are composed of single cells, which have very thin and delicate walls, and are the active agents in the absorption of nutritive matters for the plant. Some-

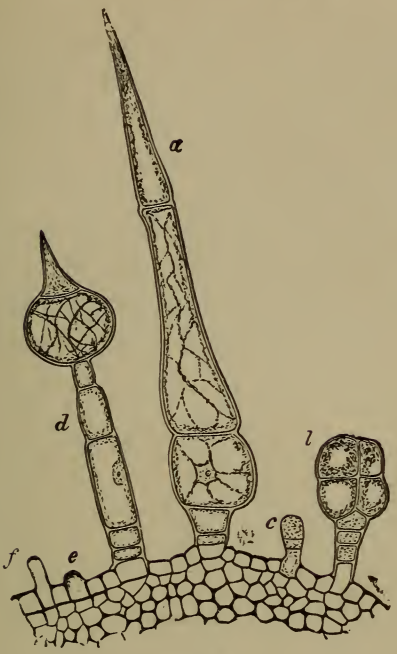


FIG. 26.

FIG. 27.

FIG. 26.—Transverse section of epidermis and underlying tissue of ovary of a Squash. *a*, hair of a row of cells; *b* and *d*, glandular hairs of different ages; *e*, *f*, *c*, hairs in the youngest stages of their development. Magnified 100 times.

FIG. 27.—A seedling Mustard-plant with its single root clothed with root-hairs; the newest (lowermost) portion of the root is not yet provided with root-hairs.

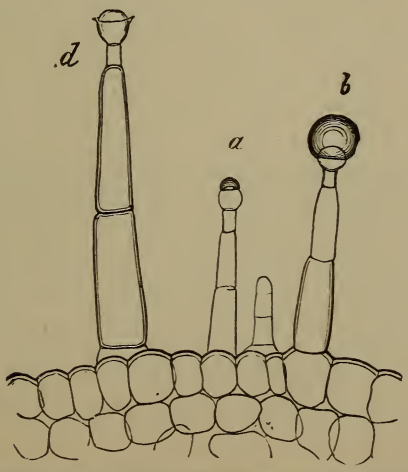


FIG. 28.—Glandular hairs of Chinese Primrose in several stages of development. Magnified 142 times.

times the terminal cell of a hair becomes changed into a secreting cell and manufactures a gummy or resinous substance. Such hairs are called Glandular Hairs and are common on many plants (Figs. 26, 28).

77. Breathing-pores (*stomata;* singular, *stoma*) consist, in most cases, of two specially modified chlorophyll-bearing cells, called the guard-cells, which have between them a cleft or slit passing through the epidermis (Fig. 29). These openings are always placed directly over interior intercellular spaces.

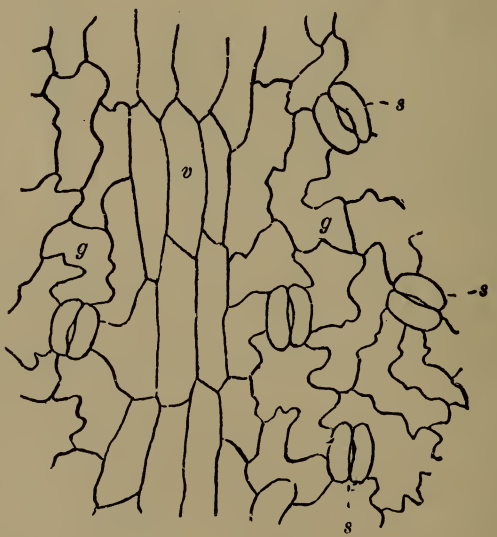


FIG. 29.—A bit of the epidermis of Wild Cucumber (Echinocystis), showing breathing-pores at *s*, *s*, *s*. At *g*, *g*, the epidermal cells are irregular; at *v*, over a vein, they are more regular. Magnified 250 times.

78. They occur on aerial leaves and stems most abundantly, being sometimes exceedingly numerous, and are exceptionally found elsewhere, as on the parts of the flowers. On submerged or undergound stems and leaves they are found in less numbers, and from true roots they are

always absent. The breathing-pores on leaves are generally confined to the lower surface, and when present on the upper they are usually much fewer in number; there are, however, some exceptions to this.

79. In the light, under certain conditions of moisture and temperature, the guard-cells become curved away from each other in their central portions, thus opening the slit and allowing free communication between the external air and that in the intercellular spaces and passages of the leaf.

The number of breathing-pores has been determined for many leaves. The following table will give an idea of their abundance on some common leaves :

	In One Square Millimeter.		In One Square Inch.	
	Upper Side.	Under Side.	Upper Side.	Under Side.
Olive (Olea europea)	0	625	0	403,125
Black walnut (Juglans nigra)	0	461	0	298,345
Red clover (Trifolium pratense)	207	335	133,515	216,075
Lilac (Syringa vulgaris)	0	330	0	212,850
Sunflower (Helianthus annuus)	175	325	112,875	209,625
Cabbage (Brassica oleracea)	138	302	88,910	194,790
Sycamore (Platanus occidentalis)	0	278	0	179,310
Lombardy poplar (Populus dilatata)	55	270	35,475	174,150
Hop (Humulus lupulus)	0	256	0	165,120
Plum (Prunus domestica)	0	253	0	163,185
Apple (Pirus malus)	0	246	0	158,670
Barberry (Berberis vulgaris)	0	229	0	147,705
Pea (Pisum sativum)	101	216	65,145	139,320
Box (Buxus sempervirens)	0	208	0	134,160
Cherry (Prunus mahaleb)	0	204	0	131,580
Thorn-apple (Datura stramonium)	114	189	73,530	121,905
Indian corn (Zea mays)	94	158	60,630	101,910
Cottonwood (Populus monilifera)	89	131	57,405	84,495
Wind-flower (Anemone trifolia)	0	67	0	43,215
Lily (Lilium bulbiferum)	0	62	0	39,990
Iris (Iris germanica)	65	58	41,925	38,410
Oats (Avena sativa)	48	27	30,960	17,415

Practical Studies.—(*a*) Strip off a bit of the epidermis of a Live-for-ever leaf. Mount it in alcohol to avoid air-bubbles, and afterwards add water and a little potassic hydrate. Epidermal cells and breathing-pores may be well seen.

(*b*) Prepare in like manner the epidermis of both upper and under surfaces of a cabbage-leaf. Note the breathing-pores on both surfaces; note also the bloom.

(*c*) Make very thin cross-sections of a cabbage-leaf (by placing a piece of leaf between two pieces of elder-pith) so as to secure cross-sections of the epidermis. Note the thickened outer wall of the epidermal cells. In some cases the separable cuticle may be seen. Now and then a breathing-pore may be seen in cross-section.

(*d*) Make similar sections of the leaf of the oleander, cactus, compass-plant, holly, or any others of a hard texture. Note in some cases (oleander and cactus) that there are several layers of epidermal cells.

(*e*) Mount in alcohol a few hairs of tickle-grass (Panicum capillare) as examples of simple one-celled hairs.

(*f*) Mount in like manner hairs of petunia, verbena, or walnut as examples of hairs made of a row of cells. Note that many of these are glandular.

(*g*) Mount in like manner hairs of the mullein as examples of greatly branched hairs.

80. The Fibro-vascular or Skeletal System.—In most of the higher plants portions of the interior tissues early become greatly differentiated into firm elongated bundles, which run through the other tissues and constitute the skeleton of the plant. They are composed for the most part of tracheary, sieve, and fibrous tissues, together with a varying amount of parenchyma, and have a general similarity of arrangement and aggregation. In a few cases milk-tissue is associated with those above mentioned. To these collections of tissues the name of Fibro-vascular Bundles has been given. They are also called Woody Bundles and Vascular Bundles, but the name first given is to be preferred.

81. In many plants the fibro-vascular bundles admit of easy separation from the surrounding tissues; thus in the

Plantain (Plantago major) they may readily be pulled out upon breaking the leaf-stalk. In the leaves of plants,

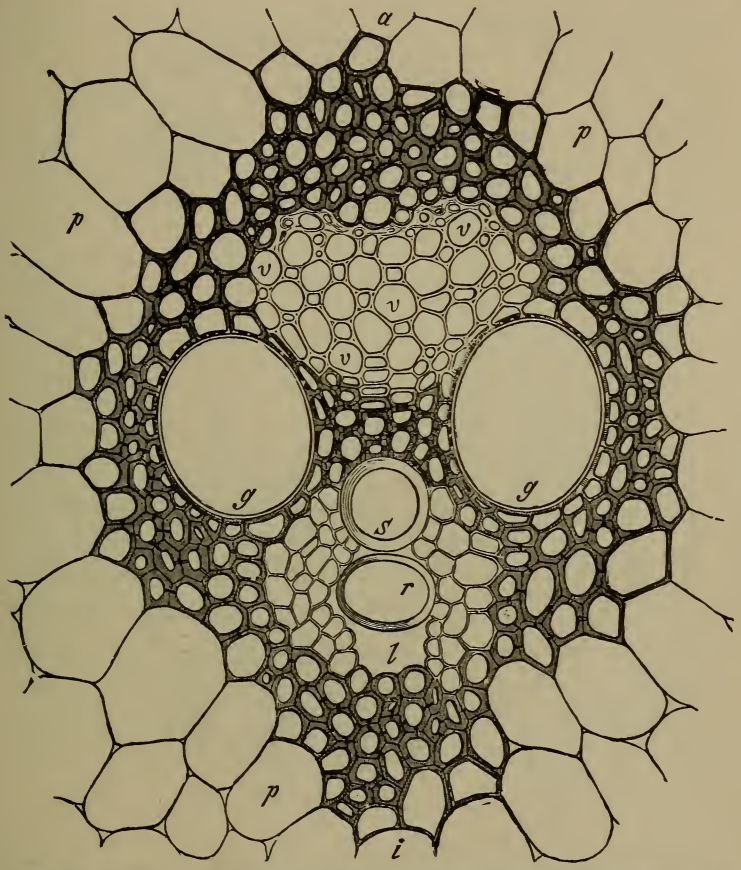


FIG. 30.—Transverse section of fibro-vascular bundle of Indian corn. *a*, side of bundle looking toward the circumference of the stem; *i*, side of bundle looking toward the centre of the stem; *g*, *g*, large pitted vessels; *s*, spiral vessel; *r*, ring of an annular vessel; *l*, air-cavity formed by the breaking apart of the surrounding cells; *v*, *v*, latticed cells, or soft bast, a form of sieve-tissue. Magnified 550 times.

where they constitute the framework, they are, by maceration, readily separated from the other tissues as a delicate network. In the stems of Indian corn the bundles run

through the internodes as separate threads of a considerable thickness.

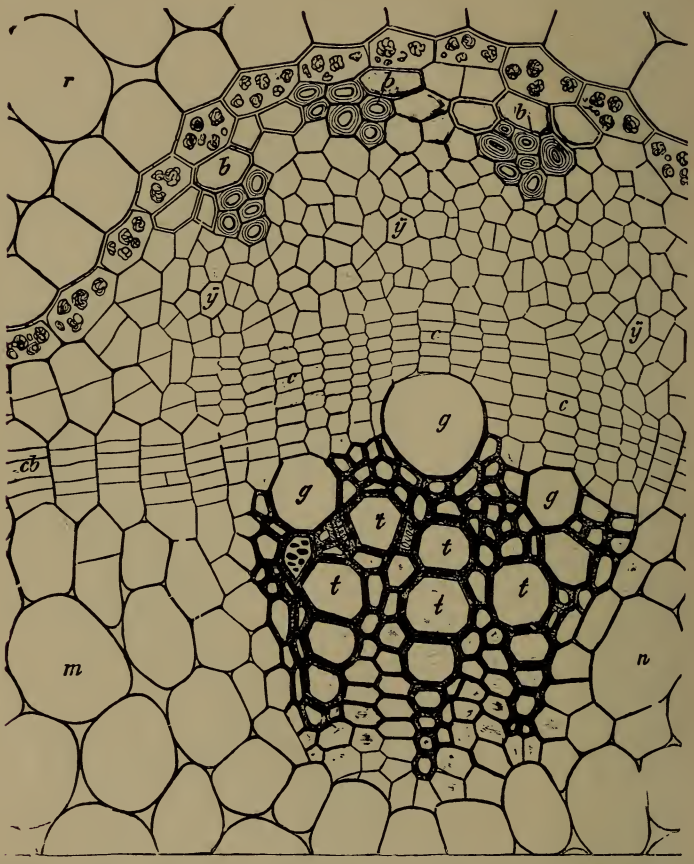


FIG. 31.—Fibro-vascular bundle of Castor-oil Plant. *t*, *t*, *g*, *g*, tracheary tissue; *y*, *y*, sieve-tissue poorly developed; *b*, *b*, bast-fibres; *c*, *c*, cambium-cells. Highly magnified.

82. In the fibro-vascular bundle of the stem of Indian corn the central portion is composed of tracheary tissue, consisting of pitted, spiral, ringed, and reticulated vessels (Fig. 30, *g*, *g*, *s*, *r*, and the tissue between *v*—*s*, *g*—*g*). Lying by the side of the tracheary tissue (on its outer side

as it is placed in the stem) is a mass of sieve-tissue, composed of latticed cells (*v*, *v*, Fig. 30). Surrounding the whole is a thick mass of fibrous tissue composed of elongated, thick-walled cells (the shaded ones in the figure).

83. In the Castor-oil Plant the limits of the fibro-vascular bundles are so poorly marked that in places it is impossible to tell whether the tissues belong to them or to the surrounding ground-tissues. The inner portion of the

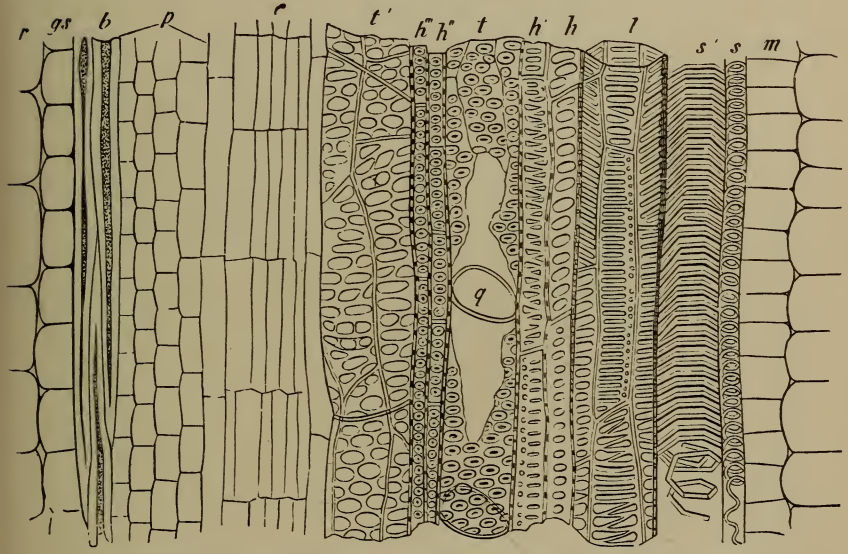


FIG. 32.—A longitudinal radial section of the bundle in Fig. 31.

bundle (*g*, *g*, *t*, *t*, Fig. 31, and *s* to *t*, Fig. 32, is made up of tracheary tissue of several varieties; on the inner edge of this tracheary portion lie several spiral vessels (*s*, *s*, Fig. 32); next to these, on their outer side, are scalariform and pitted vessels (*t*, *t*, *g*, *g*, Fig. 31; *l*, *t*, *t'*, Fig. 32), intermingled with elongated cells, whose walls are pitted (*h*, *h'*, *h''*, *h'''*, Fig. 32). The last-named are clearly related to the vessels which surround them, and from which

they differ only in their less diameter, and in having imperforate horizontal or oblique partitions. They are doubtless properly classed with the tracheïds (see paragraph 54).

84. On the outer side of the tracheary portion just described lies a mass of narrow, somewhat elongated, thin-walled cells, which constitute a true meristem-tissue, to which the name of *cambium** has been given (*c*, *c*, Figs. 31 and 32). Next to the cambium lie, in order, sieve-tissue and soft tissue (parenchyma); these do not occupy separate zones, but are more or less intermingled, forming a mass called the Soft Bast (*y*, *y*, *y*, Fig. 31, and *p*, Fig. 32). The sieve-tissue includes sieve-tubes and cambiform or latticed cells. In the extreme outer border of the bundle is a mass of fibrous tissue (*b*, *b*). The layer of starch-bearing cells just outside of the last-named tissue is the so-called "bundle-sheath."

85. In most higher flowering plants the fibro-vascular bundles of the stems have a structure essentially like that of the Castor-oil Plant just described. In them it is evident at a glance that the bundle is divided into two somewhat similar portions, an inner and an outer, by the cambium-zone. Nägeli, who first pointed out these divisions, named the inner one the Xylem portion, because from it the wood of the stem is formed; the outer he named the Phloëm portion, for the reason that it develops into bark. If we wish to be less technical we may call the first the Wood portion, and the second the Bark portion.

86. In some cases the xylem and phloëm are composed of corresponding tissues, (1) Vessels, (2) Fibres, and (3)

* Cambium, a low-Latin word meaning a liquid which becomes glutinous. The term was introduced when the real structure of the part to which it was applied was not understood.

Soft Cells. The vessels are the tracheary tissue in the xylem and the sieve-tissue in the phloëm. The fibrous tissue of the xylem is the variety with the shorter and harder fibres, known as wood-fibres; that of the phloëm is composed of the longer and tougher bast-fibres. The soft tissue (parenchyma) of the two portions is much alike.

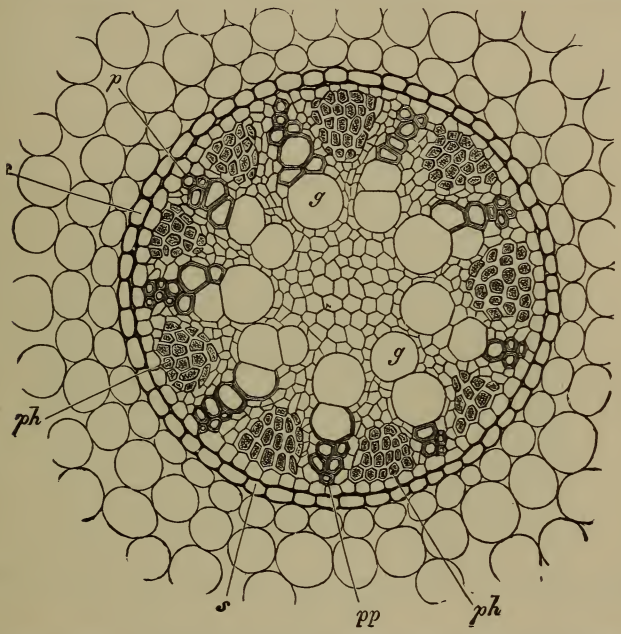


FIG. 33.—Fibro-vascular bundle of root of Sweet Flag (Acorus). *pp*, plates of tracheary tissue; *g*, *g*, pitted vessels; *ph*, sieve-tissue; *s*, bundle-sheath.

87. In the fibro-vascular bundle of the young roots of Sweet Flag there are many radially placed plates of tracheary tissue (*pp*, Fig. 33), which alternate with thick masses of sieve-tissue (*ph*). Between these alternating tissues, and within the circle formed by them, there is a mass of soft tissue. The whole bundle is separated from the large-celled soft tissue of the root by a well-marked bundle-

sheath (*s*); the latter is bounded interiorly by a layer of active thin-walled cells (the pericambium), from which new roots originate. In the older roots the central cell-mass is transformed into stony tissue.

88. The bundle of the larger Club-mosses (Lycopodium) contains several parallel plates of tracheary tissue (Fig. 34). Between the tracheary plates there is in each case a row of sieve-tubes imbedded in a lignified tissue composed of elongated cells (stony or fibrous tissue?). Around this

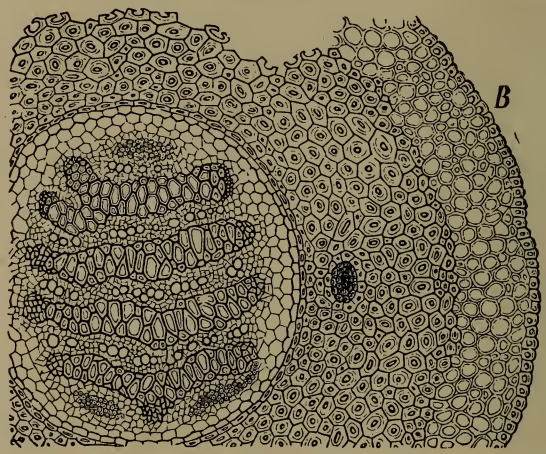


FIG. 34.—Magnified cross-section of the stem of a larger Club-moss (Lycopodium complanatum), showing a fibro-vascular bundle.

central fibro-vascular portion there is a layer of soft tissue (parenchyma), and outside of this a bundle-sheath, exterior to which lies a thick mass of fibrous tissue completely enveloping all the previously described tissues.

89. The bundle in the smaller Club-mosses (Selaginella) is much like a single plate of the preceding. There is in each bundle a central plate of tracheary tissue, consisting of a few narrow spiral vessels in its two edges and a remaining mass of scalariform vessels (Fig. 35). The tra-

cheary portion is surrounded by a layer of elongated, thin-walled tissue which is, at least in part, a sieve-tissue. In this and allied species the bundles are curiously isolated from the surrounding ground-tissues of the stem.

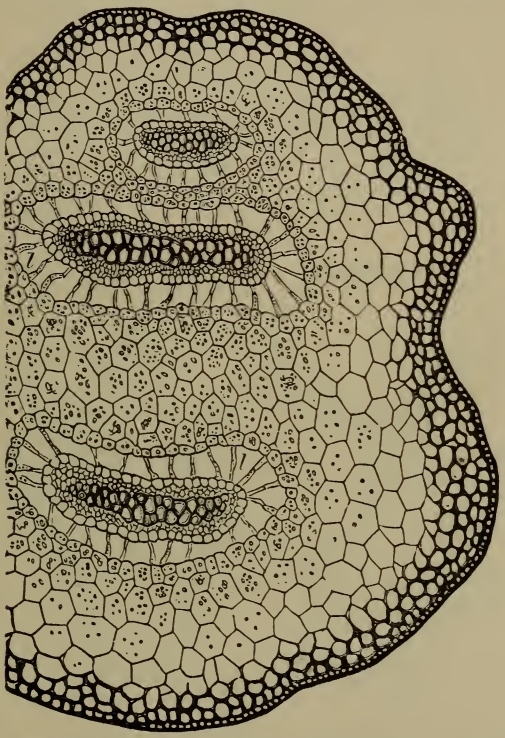


FIG. 35.—Magnified cross-section of the stem of a smaller Club-moss (Selaginella inæquifolia), showing three bundles.

90. The fibro-vascular bundle of the underground stem of the common Brake-fern (Pteris) is composed of tracheary, sieve, and soft tissues and a small amount of poorly developed fibrous tissue. In transverse section the bundle has usually an elliptical outline. The great mass of the bundle is made up of large scalariform vessels, which occupy its interior (*g*, *g*, *g*, Fig. 36). Enclosed in the sca-

lariform tissue are masses of soft tissue (parenchyma) and a few spiral vessels, the latter occurring near the foci of the elliptical cross-section of the bundle (*s*). Surrounding or partly surrounding the tracheary portion of the bundle is a layer of sieve-tubes (*sp*), separated from the large sca-

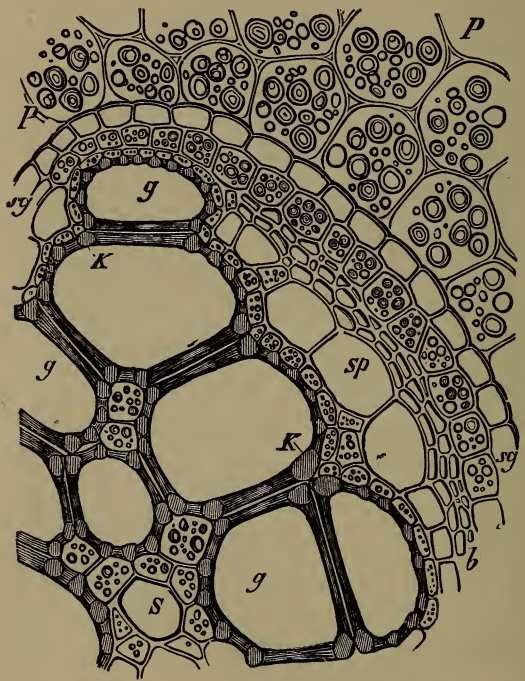


FIG. 36.—Part of a transverse section of the fibro-vascular bundle of the underground stem of the common Brake-fern (Pteris aquilina). *s*, spiral vessel; *g*, *g*, scalariform vessels; *sp*, sieve-tissue; *b*, fibrous tissue; *sg*, bundle-sheath.

lariform vessels by a layer of parenchyma. Outside of the sieve-tissue is a mass of fibrous tissue (*b*), which is itself bounded externally by another layer of parenchyma. The whole bundle is surrounded by a bundle-sheath.

91. A noticeable feature in the structure of this bundle is that the tissues have a concentric arrangement: the tra-

cheary tissue is encircled by a layer of parenchyma; this by one of sieve-tissue; this again by fibrous tissue; and so on.

92. De Bary's classification of fibro-vascular bundles is useful in designating their general plan. He includes all forms under three kinds, viz., (1) the Collateral bundle, which has one mass of xylem by the side of a single mass of phloëm; (2) the Concentric bundle, which has its tissues arranged concentrically around one another; (3) the Radial bundle, which has its tissues arranged radially about its axis.

93. The development of the fibro-vascular bundle takes place in this wise: in the previously uniform primary meristem there arises an elongated mass of cells, constituting the Procambium of the bundle; as it grows older the cells, which were at first alike, become changed into the vessels, fibres, and other elements of the bundle-tissues. In most higher flowering plants this change begins on the two sides of the bundle—i.e., on the outer edge of the phloëm and the inner edge of the xylem; from these points the change into permanent tissue advances from both sides toward the centre of the bundle.

94. In some cases all of the procambium is changed into permanent tissue, forming what is termed the *closed* bundle; in other cases there is left between the phloëm and xylem a narrow zone of the procambium (now called the cambium), forming what is known as the *open* bundle. Closed bundles are thus incapable of further growth, while open bundles may continue to grow indefinitely.

95. The fibro-vascular bundles of leaves and the reproductive organs are quite generally reduced by the absence of one or more tissues; this reduction may be so great as

to leave but a single tissue, which in many cases is composed of only a few spiral vessels or tracheïds (Fig. 37). In other cases, instead of spiral vessels the bundle may consist of a few fibres of bast; or of elongated, thin-walled cells, which are doubtless to be regarded as meristem-cells which failed to fully change into one of the ordinary permanent tissues: this last is a very common accompaniment of reduced bundles.

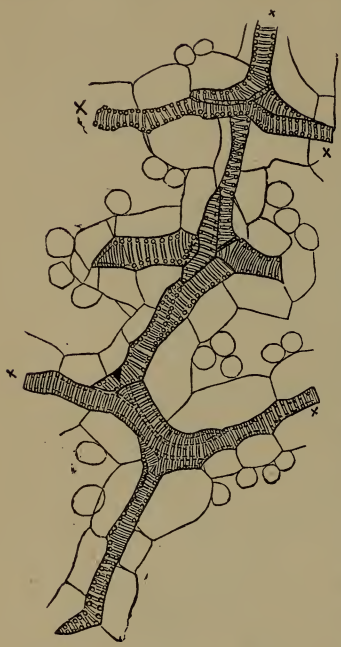


FIG. 37.—Terminal portions of fibro-vascular bundles in a leaf, reduced to tracheïds and spiral vessels.

Practical Studies.—(*a*) Break a stem of Indian corn and note with the naked eye the tough string-like fibro-vascular bundles which run through the soft tissues. Examine in like manner the fibro-vascular bundles of the common door-yard Plantain.

(*b*) Make a very thin cross-section of the stem of Indian corn and, using the microscope, study the bundles carefully by comparing with Fig. 30. In bundles from young stems the fibrous tissue will not show as good a development as in the figure.

(*c*) Now make thin longitudinal sections of a bundle in such a manner as to have the sections pass through *a* and *i* in the figure. This may be done by slicing the stem in a longitudinal radial direction. Study again by comparison with the figure and with the previous specimen.

(*d*) Make thin longitudinal sections of a bundle at right angles to the last (by longitudinal tangential sections of the stem).

(*e*) Study in like manner the bundles of sugar-cane and asparagus.

(*f*) Study by similar sections the bundles of the young stem of the Castor-oil Plant and Red Clover. The latter is very convenient for study, as the uppermost joints will furnish as young bundles as

are required, while lower down all older stages may be obtained. In these note the cambium-zone.

(*g*) Make very thin cross-sections of a root of germinating Indian corn. The first section should be made within a few millimeters of the root-tip. Others should then be made at a greater distance. By staining the specimens with carmine the sieve-regions may be demonstrated better. Note the bundle-sheath.

(*h*) Study in like manner the bundle in the stem of the Club-mosses (some of the species are known as Ground-pines), and if possible make comparison with sections of the smaller Club-mosses (grown in greenhouses often under the name of Lycopodium, although they are in reality species of Selaginella).

(*i*) Dig up the underground stem of the common Brake-fern (Pteris); preserve what is not wanted immediately in alcohol. The bundles may be seen by the naked eye by making a clean cross-cut and examining carefully in the region immediately surrounding the two dark masses of fibrous tissue. Make thin cross-sections and study with the microscope, comparing with Fig. 36. Longitudinal sections in two planes should be made as in *c* and *d* above.

(*j*) Make very thin longitudinal sections of some of the reduced bundles which constitute veins and veinlets of leaves, e.g., in geranium and primrose.

(*k*) Make similar sections of the bundles of petals, e.g., fuchsia.

(*l*) Soak petals of fuchsia for several days in potassic hydrate, then wash in water and carefully mount in pure water. The reduced bundles may generally be well seen by this treatment.

96. The Fundamental System of Tissues.—This system includes all the tissues which in any part of a plant frequently make up the bulk of that part, but are not included in the epidermal or fibro-vascular systems. Thus if from any stem, for example, we should strip off the epidermis and then pull out the fibro-vascular bundles, that which remained would be the Fundamental System of Tissues. In those plants (of the lower classes) which have no fibro-vascular bundles everything inside of the epidermis belongs to the fundamental system. On the other hand, in the stems of our woody trees there is but very little of the fundamental system present, making up the very small

pith and the thin plates (medullary rays) running radially through wood and bark.

97. In its fullest development the fundamental system may contain soft tissue (parenchyma) of various forms, thick-angled tissue, stony tissue, fibrous tissue, and milk-tissue. Their arrangement, within certain limits, presents a considerable degree of similarity in nearly related groups of plants, but this is by no means as marked as in the case of the fibro-vascular system.

98. (1) Soft tissue (parenchyma) is the most constant of the fundamental tissues; it makes up the whole of the interior plant-body in those plants where there has been no differentiation into more than one tissue, and it is present in varying amounts in all plants up to and including the highest.

99. (2) Thick-angled tissue (collenchyma) when present, as it generally is in the stems and leaves of flowering plants, is always either in contact with or near to the epidermis.

100. (3) Stony tissue (sclerenchyma) is common beneath the epidermis of the stems and leaves of flowering plants and ferns, and the stems of mosses. It sometimes appears to replace thick-angled tissue. Some elongated forms of stony tissue are scarcely to be distinguished from fibrous tissue.

101. (4) Fibrous tissue occurs in some leaves and stems near to the epidermis. In ferns it forms thick band-like masses, giving strength to the stems.

102. (5) Milk-tissue (laticiferous) may occur, apparently, in any portion of the fundamental system of flowering plants.

103. It is thus seen that in general the tissues of the

fundamental system are so disposed that the periphery is harder and firmer than the usually soft interior, although there are many exceptions. This general structure has given rise to the term Hypoderma for those portions of the fundamental system which lie immediately beneath or near to the epidermis. Hypoderma is not a distinctly limited

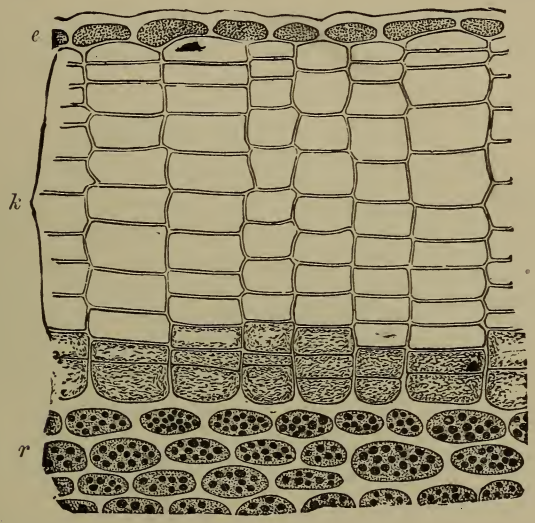


FIG. 38.—Transverse section of one-year-old stem of Ailanthus. *e*, epidermis; *k*, cork-cells; *r*, inner green cells; between *k* and *r* a layer of cells filled with protoplasm, called the phellogen, or cork-cambium. Magnified 350 times.

portion—in fact, it is often difficult to say how far it does extend; however, it usually includes several, or even many, layers of cells, or the whole of each of the tissue-masses (e.g., thick-angled, stony, and fibrous tissues, etc.) which immediately underlie the epidermis.

104. Cork.—Within the zone which the hypoderma includes there frequently takes place a peculiar development of the young parenchyma, giving rise to layers of dead cells, whose cavities are filled with air only. The walls in

some cases (e.g., the cork-oak) are thin and weak, while in others (e.g., the beech) they are much thickened, and in all cases they are nearly impermeable to water. True cork is destitute of intercellular spaces, its cells being of regular shape (generally cuboidal) and fitted closely to each other (Fig. 38).

105. Cork-substance is formed by the repeated subdivision of the cells of a meristem layer of the fundamental

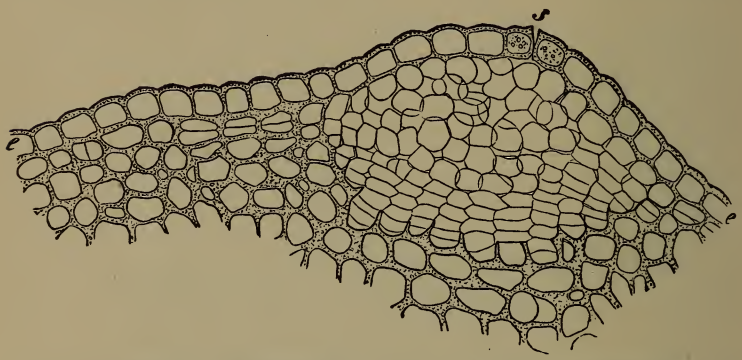


FIG. 39.—Cross-section through a lenticel of Birch. *e*, epidermis; *s*, a breathing-pore. Magnified 280 times.

tissue (Fig. 38); these continue to grow and divide by partitions parallel to the epidermis, forming layers of cork with its cells disposed in radial rows (Fig. 38, *k*). Shortly after their formation the cork-cells lose their protoplasmic contents, while beneath them new cells are constantly being cut off from the cells of the generating layer; in this way the mass of dead cork-tissue is formed and pushed out from its living base.

106. The generating tissue is called the Cork-cambium, or Phellogen; it occurs not only in the hypoderma, but in any other part of the fundamental system, and in the secondary fibro-vascular bundles. When a living portion of

a plant is injured, as by cutting, the uninjured cells beneath the wound often change into a layer of cork-cambium, from which a protecting mass of cork is then developed.

107. A little cork-cambium sometimes forms immediately beneath a breathing-pore, and produces a minute mass of cork which pushes out and finally ruptures the epidermis, forming Lenticels (Fig. 39). Lenticels are of frequent occurrence on the young branches of birch, beech, cherry, elder, lilac, etc., and may be distinguished by the naked eye as slightly elevated roughish spots, usually of a different color from the epidermis.

Practical Studies.—(*a*) Make cross-sections of the stem of the pumpkin. Note that the fundamental portion contains soft, fibrous and thick-angled tissues.

(*b*) Make a similar section of milkweed (Asclepias) stem. Note that the fundamental portion contains soft, thick-angled, and milk tissue.

(*c*) Make cross and longitudinal sections of the leaf of the Scotch or Austrian Pine. Note the fibrous tissue in the hypodermal portion.

(*d*) The stone-cells in the pith of the apple-twig are good examples of this tissue in the fundamental system.

(*e*) Examine the cells which make up the medullary rays of the old wood of the oak or beech. They will be found to be stony tissue. In young wood they are thin-walled and thus constitute soft tissue (parenchyma).

(*f*) Make very thin sections (in different planes) of commercial cork (the product of the Cork-oak of Southern Europe) and mount in alcohol to expel the air-bubbles. Note the thin walls and the approximately cubical shape of the cells.

(*g*) Make very thin cross-sections of a young twig of the apple, snowball, or birch, so as to cut through a young lenticel. Mount in alcohol as before.

108. Intercellular Spaces.—In addition to the cavities and passages which are formed in the plant from cells and their modifications, there are many important ones which are intercellular and which at no time were composed of cells. In some cases they so closely resemble the cavities derived from cells that it is with the greatest difficulty that

their real nature can be made out. In their simplest form they are the small irregular spaces which appear during the rapid growth of parenchyma-cells (Fig. 40); from these to the large regular canals which are common in many water-plants there are all intermediate gradations.

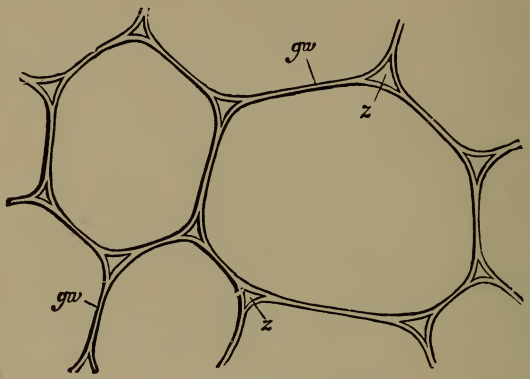


FIG. 40.—A bit of the soft tissue of the pith of the stem of Indian corn; transverse section. *gw*, simple plate of cellulose, forming the partition-wall between two cells; *z*, *z*, intercellular spaces caused by splitting of the walls during rapid growth. Magnified 550 times.

109. In leaves, especially in the soft tissue of the under portion, there are usually many large irregular spaces between the cells; they are in communication with the external air through the breathing-pores, and contain only air and watery vapor. The leaf-stalks and stems of many aquatic plants contain exceedingly large air-conducting intercellular canals, which occupy even more space than the surrounding tissues (Fig. 41). In the rushes, water-lilies, and water-plantains they are so large as to be readily seen by the naked eye. These all are in communication with the external air through the breathing-pores and the intercellular spaces of the leaves.

110. Some intercellular spaces serve as reservoirs of gummy or resinous secretions. Such ones are surrounded by

secreting cells which manufacture the gummy or resinous matter and then exude it into the cavity (Fig. 42). The

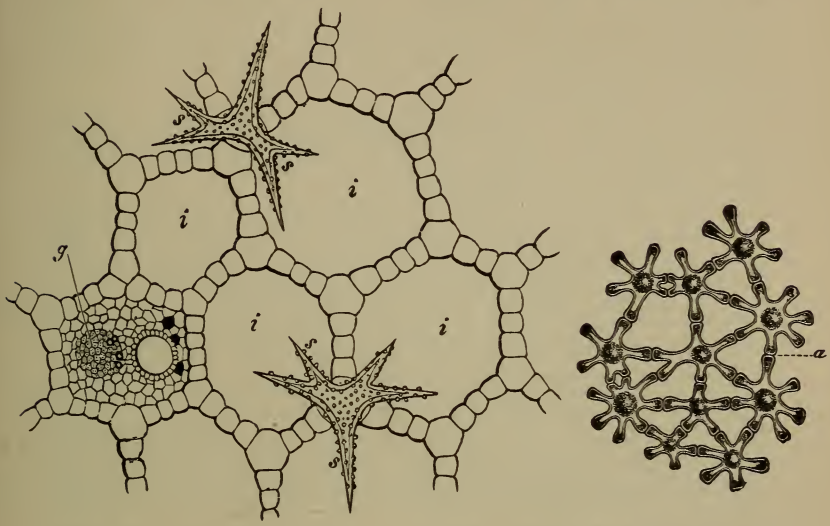


FIG. 41.—Intercellular spaces. *A*, in leaf-stalk of a Water-lily; *s*, star-shaped cells. *B*, in stem of a Rush; the cells here all star-shaped. Both cross-sections.

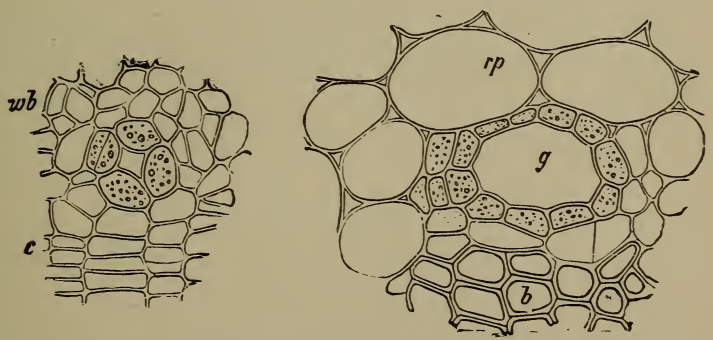


FIG. 42.—Transverse sections of young stem of Ivy (Hedera helix). *A*, young intercellular gum-canal, surrounded by four cells; *c*, cambium; *B*, fully developed canal, *g*; *b*, bast. Magnified 800 times.

Turpentine-canals of the pines and spruces are of this nature, the well-known turpentine being secreted by one or more

rows of cells which border the rather large canals. The function of these canals and their secretion has not yet been made out with certainty. The recent suggestion that the turpentine may be for the coating over of wounds is by no means satisfactory.

Practical Studies.—(*a*) Make extremely thin cross-sections of the stem of Indian corn, using a very sharp scalpel (or razor). Note the small triangular intercellular spaces.

(*b*) Make thin cross-sections of an apple-leaf and note the intercellular spaces of the lower half of the section. Remember that in this leaf there are nearly 250 breathing-pores to every square millimetre of lower surface, while there are none at all upon the upper.

(*c*) Study in cross-section the intercellular spaces in the stem of the Rush (Juncus), and the leaf-stalks of water-lilies, water plantains (Alisma), and arrowheads (Sagittaria).

(*d*) Study turpentine-canals in very thin cross-sections of leaves of pines and spruces. The larger-leaved species, as Scotch, Austrian, or Scrub pine, and the Balsam-fir, are the most satisfactory.

(*e*) Make cross-sections of the twigs of White pine and study turpentine canals in bark and wood.

(*f*) Study the oil-receptacles in the fresh rind of the orange and lemon by thin cross-sections. These are not strictly intercellular, but are formed by the breaking away of the secreting cells, thus leaving a cavity.

(*g*) The similarly-formed oil-receptacles of the mints and the garden Fraxinella may be studied by making very thin cross-sections of the leaves.

CHAPTER IV.

THE PLANT-BODY.

111. Differentiation of the Plant-body.—The cells, tissues, and tissue-systems described in the preceding pages are variously arranged in the different groups of the vegetable kingdom to form the *Plant-body*. The simplest plants are single cells or masses of similar cells; in those next higher the cells are aggregated into a few simple tissues; while still above these the tissues are grouped into tissue-systems.

112. With this internal differentiation there is a corresponding differentiation of the external plant-body. The lower plants are not only simpler as to their internal structure, but they are so as to their external form as well. The higher plants are as much more complex than the lower ones as to their external parts as they are in regard to their tissues and tissue-systems.

113. Members of the Plant-body.—In the lowest groups of plants the simple plant-body has no members; the single- or few-celled seaweed has no parts like root, stem, or leaf; it is a unit as to its external form. In the higher groups, on the contrary, the plant-body is composed of several or many members which are less or more distinct. In those plants in which they first appear, the members are not clearly or certainly to be distinguished from the general

plant-body; but in the higher groups they become distinctly set off, and are eventually differentiated into a multitude of structural and functional forms.

114. Every plant in its earliest (embryonic) stages is simple and memberless; and every member of any of the higher plants is at first indistinguishable from the rest of the plant-body; it is only in the later growth of any member that it becomes distinct; in other words, every member is a modification of, and development from, the general plant-body.

115. Likewise, where equivalent members have a different particular form or function, it is only in the later stages of growth that the differences appear. All equivalent members are alike in their earlier stages, whether, for example, they eventually become broad green surfaces (foliage-leaves), bracts, scales, floral envelopes, or the essential organs of the flower.

116. Generalized Forms.—These facts make it necessary to have some general terms for the parts of the plant-body which are applicable to them in all their forms. We must have, for example, a term so generalized as to include foliage-leaves, bracts, scales, floral envelopes, and all the other forms of the so-called leaf-series. So, too, there is need of a term to include stems, bulb-, bud- and flower-axes, root-stocks, corms, tubers, and the other forms of the so-called stem-series.

117. By a careful study of the members of the higher plants we find that they may be reduced to four general forms, viz., (1) *Caulome,* which includes the stem and the many other members which are found to be its equivalent; (2) *Phyllome,* including the leaf and its equivalents; (3) *the Root,* which includes, besides ordinary subterranean

roots, those of epiphytes, parasites, etc. (4) *Trichome*, which includes all outgrowths or appendages of the surface of the plant, as hairs, bristles, root-hairs, etc. Caulome and Phyllome together constitute the *Shoot*, so that in common, terrestrial, higher plants the plant-body is composed of the Shoot in the air, and the Root in the ground, with Trichomes on both portions.

118. As indicated above, in the lower plants the differentiation into members is not as marked as in the higher, and in passing downward in the vegetable kingdom groups are reached in which it is inappreciable, and finally in which it is entirely wanting: such an undifferentiated plant-body is called a *Thallome*, and may properly be regarded as the original form, or prototype.

119. Thallome.—This properly includes all cases in which the plant-body is a mass of cells, with no differentiation of members, but for convenience we may include also the single plates, and rows of cells, and even the single cells. Plants composed of rows or plates of cells frequently show no indication whatever of a division into members; but in some cases there is a little differentiation, though not carried far enough to give rise to members.

120. In the larger seaweeds there is sometimes so much of a differentiation that it becomes difficult to say why certain parts ought not to be called members. Forms of this kind are instructive, as showing that the passage from the thallome plant-body to that in which members are differentiated is by no means an abrupt or sudden one.

121. Caulome.—By this general name we designate all axial members of the plant. In the more obvious cases the caulome is the axis which bears leaves (foliage), and in this form it constitutes

(1) *The Stem;* branches are only stems which originate laterally upon other stems.

The other caulome forms are:

(2) *Runners,* which are bract-bearing, slender, weak, and trailing.

(3) *Root-stocks,* which are bract- or scale-bearing, usually weak, and generally subterranean.

(4) *Tubers,* which are bract- or scale-bearing, short and thickened, and subterranean.

(5) *Corms,* which are leaf-bearing, short and thickened, and subterranean.

(6) *Bulb-axes,* which are leaf-bearing, short and conical, and subterranean.

(6) *Flower-axes,* which are bract-, perianth-, stamen-, and pistil-bearing, short and usually conical and aerial.

(8) *Tendrils,* which are degraded, slender, aerial caulomes, nearly destitute of phyllomes.

(9) *Thorns,* which are degraded, thick, conical, aerial caulomes, nearly destitute of phyllomes.

122. Phyllome.—The phyllome is always a lateral member upon a caulome. It is usually a flat expansion and extension of some of the tissues of the caulome. Its most common form is

(1) The *Leaf* (foliage), which is usually large, broad, and mainly made up of chlorophyll-bearing tissue.

The other phyllome forms are:

(2) *Bracts,* which are smaller than leaves, generally green.

(3) *Scales,* which are usually smaller than leaves, wanting in chlorophyll-bearing tissue, and generally with a firm texture.

(4) *Floral envelopes,* which are variously modified, but

generally wanting in chlorophyll-bearing tissue, and with generally a more delicate texture.

(5) *Stamens,* in which a portion of the soft tissue develops male reproductive cells (pollen).

(6) *Carpels,* bearing or enclosing female reproductive organs (ovules).

(7) *Tendrils* and (8) *Spines,* which are reduced or degraded forms, composed of the modified fibro-vascular bundles and a very little soft tissue; in the first the structures are weak and pliable, in the latter stout and rigid.

The altogether special modifications of the phyllome, as in *pitchers* and *cups,* will be noticed hereafter.

123. Root.—The root is that portion of the plant-body which is clothed at its growing point with a root-cap. In ascending through the vegetable kingdom roots are the latest of the generalized forms to make their appearance, and in the embryo they appear to be formed later than caulome and phyllome. They present fewer variations than any of the other generalized forms. The ordinary

(1) *Subterranean roots* of plants are typical. They differ but little from one another in whatever plants they may be found.

The other root-forms are:

(2) *Aerial roots,* which project into the air, and often have their epidermis peculiarly thickened, as in the epiphytic orchids.

(3) *Roots of Parasites,* which are usually quite short, and in some cases provided with sucker-like organs, by means of which they absorb food from their hosts.

124. Trichome.—The trichome is a surface appendage consisting of one or more cells usually arranged in a row

or a column, sometimes in a mass. Its most common forms are met with in

(1) The *Hairs* of many plants. (See page 42.)

The other trichome forms are:

(2) *Bristles,* each consisting of a single pointed cell or

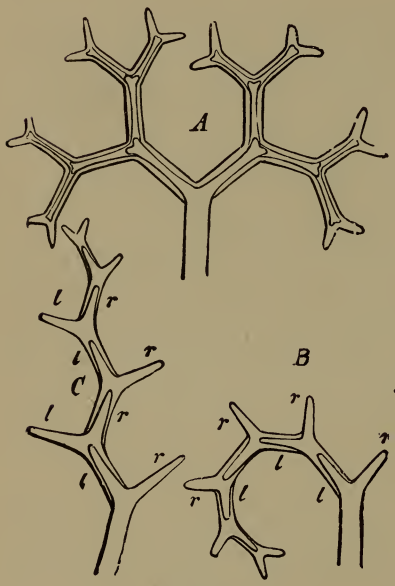


FIG. 43.

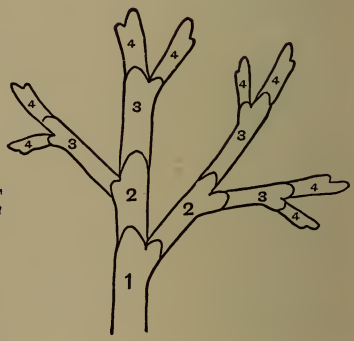


FIG. 44.

FIG. 43.—Diagrams of dichotomous branching. *A*, normal dichotomy, in which each branch is again dichotomously branched; *B*, helicoid dichotomy, in which the right-hand branch, *r*, does not develop further, while the left-hand one, *l*, is in every case again branched; *C*, scorpioid dichotomy, in which the branches are alternately further developed.

FIG. 44.—Diagram of botryose monopodial branching. The numerals indicate the "generations."

a row of cells, whose walls are much thickened and hardended.

(3) *Prickles,* like the last, but stouter, and usually composed of a mass of cells below.

(4) *Scales,* in which the terminal cell gives rise by fission to a flat scale, which soon becomes dry.

(5) *Glands,* which are generally short, bearing one or more secreting cells.

(6) *Root-hairs,* which are long, thin, single-celled (in mosses a row of cells), and subterranean.

(7) *Sporangia* of ferns and their relatives, some of whose interior cells develop into reproductive cells (spores).

(8) *Ovules* of flowering plants one or more of whose cells develop into reproductive cells (embryo-sacs).

125. General Modes of Branching of Members.—All the members of the plant-body may branch. This branching always follows one of two general methods. In the one the apex of the growing member divides into two new growing points, from which branches proceed: this is the *Dichotomous* mode of branching (Fig. 43). In the other the new growing points arise laterally while the original apex still retains its place and often its growth: this is the *Monopodial* mode of branching (Fig. 44.) Both modes are subject to many modifications, the most important of which are briefly indicated in the following table; and moreover a member may branch for a time dichotomously and then monopodially, or the reverse.

A. DICHOTOMOUS.

1. *Forked dichotomy,* in which both branches of each bifurcation are equally developed (Fig. 43, *A*).
2. *Sympodial dichotomy,* in which one of the branches of each bifurcation develops more than the other.
   - *a. Helicoid sympodial dichotomy,* in which the greater development is always on one side (Fig. 43, *B*).
   - *b. Scorpioid sympodial dichotomy,* in which the greater development is alternately on one side and the other (Fig. 43, *C*.)

B. MONOPODIAL.

1. *Botryose monopodium,* in which, as a rule, the axis continues to grow, and retains its ascendency over its lateral branches (Fig. 44).

2. *Cymose monopodium*, in which the axis soon ceases to grow, and is overtopped by one or more of its lateral branches.
   a. *Forked cymose monopodium*, in which the lateral branches are all developed (Fig. 45, C).
   b. *Sympodial cymose monopodium*, in which some of the lateral branches are suppressed; this may be—
      b'. Helicoid, when the suppression is all on one side (Fig. 45, *D*); or—
      b''. Scorpioid, when the suppression is alternately on one side and the other (Fig. 45, *A* and *B*).

Practical Studies.—(*a*) Mount and examine under a low power of the microscope or by the naked eye alone the following in order as

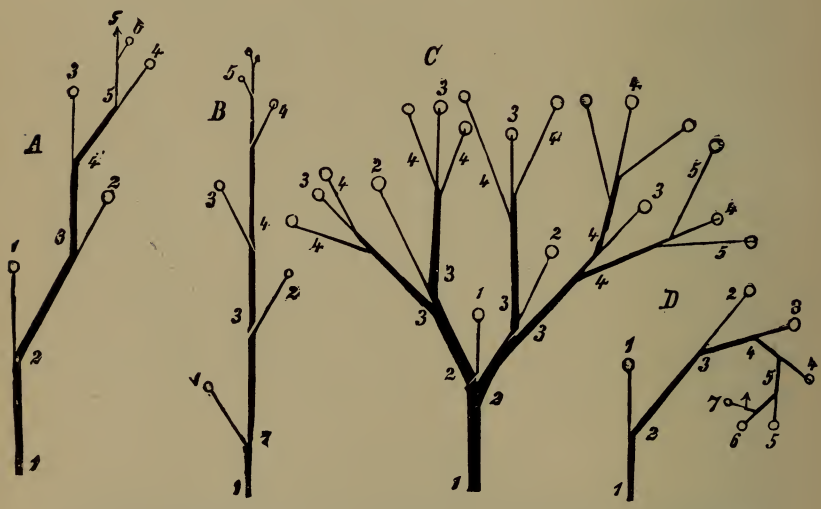


FIG. 45.—Diagrams of cymose monopodial branching. *A* and *B*, scorpioid cymes; *C*, forked cymose monopodium, the compound or falsely dichotomous cyme (called also the *dichasium*); *D*, helicoid cyme.

examples of thallomes: 1, Groen Slime; 2, Pond Scum; 3, the first stage of a fern "seedling" (little flat green growths, 3–5 mm. across, which often appear on the earth near ferns in greenhouses); 4, Sea-lettuce (Ulva); 5, Irish moss (Chondrus), the latter showing a much-lobed form.

(*b*) Study as examples of caulome forms the following in order 1, the stem of Lamb's Quarters, or Indian corn; 2, runners of the strawberry; 3, root-stocks of blue grass; 4, tubers of the potato; 5, corms of Gladiolus, or Indian turnip; 6, bulb-axis of the onion; 7,

flower-axis of anemone, buttercup, tulip, or lily; 8, tendrils of the grape, or Virginia creeper; 9, thorns of honey-locust, or plum.

(*c*) Study as examples of phyllome forms: 1, leaf of apple, cherry, or Indian Corn, etc.; 2, bracts of flower-cluster of cress, sweet-william, golden-rod, or aster; 3, scales of buds of hickory or lilac; 4, floral envelopes of anemone, buttercup, tulip, or lily; 5, stamens of any of the above; 6, carpels of anemone, buttercup, columbine, etc.; 7, tendrils of pea, or vetch; 8, spines of thistles.

(*d*) Study for root-forms: 1, roots of seedling cabbages, radishes, etc.; 2, aerial roots of greenhouse orchids; 3, parasitic roots of mistletoe.

(*e*) Study as examples of trichome forms: 1, hairs of petunia or verbena; 2, bristles of tickle-grass; 3, prickles of the hop; 4, scales of the buffalo-berry, or elæagnus; 5, glands of the petunia or walnut; 6, root-hairs of seedling cabbages, radishes, etc.; 7, sporangia of common polypody fern; 8, ovules of anemone, buttercup, columbine, bouncing-bet, etc.

CHAPTER V.

PLANT PHYSIOLOGY.

126. Definition.—Plants not only have members and organs, which are composed of cells, tissues and tissue-systems, but in addition, they have activities, sometimes pertaining to the whole plant, sometimes to the members, the tissues, or the cells. A study of these activities is Physiology.

127. Divisions of Physiology.—The activities of plants may be considered under five heads, viz.; Nutrition, Growth, The Physics of Vegetation, Plant Movements, and Reproduction.

NUTRITION.

128. Absorption.—Nutrition includes all those activities which have to do with the supply of matter to meet the wants of living cells. The life of a cell involves the use of matter, and as long as a cell is living it must have a continual supply of certain substances. Accordingly we find that every mass of living protoplasm under favorable conditions is continually absorbing watery solutions. Imbibition is one of the most pronounced of the properties of living protoplasm, and its absence is one of the marked distinctions between living and dead cells. Along with the water thus absorbed, are taken in the various substances dissolved in it; these may have been solids dissolved in the water, or liquids, or even gases. It appears,

however, that solutions are not always absorbed without modification; thus, of a 2-per-cent solution outside of the cell proportionately more water than dissolved substance may be absorbed, so that the solution in the cell may have a strength of no more than 1 per cent; or the opposite may occur, and the strength of the solution in the cell may be greater than that outside of it. This selective power may even bring about chemical changes in the watery solutions, when the plant-cells absorb certain constituent parts of the chemical compounds. In simple plants all parts of the plant-body absorb from the surrounding water equally, and this appears to be the case with all true aquatics. In terrestrial plants, however, the absorption of watery solutions is almost or entirely confined to the parts in the ground (hairs or roots Fig. 46).

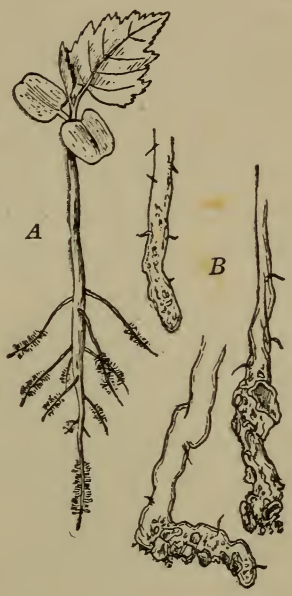


FIG. 46.—*A*, seedling plant of Water-beech (Carpinus) slightly reduced. *B*, ends of root-hairs of wheat, × 400. (After Sachs.)

129. Plant-food.—The most important elements which are used in the nutrition of plants, or which, in other words, enter into their food, are Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, Iron, and Potassium. These all appear to be necessary to the life and growth of the plant, and if any of them are wanting in the water, soil, or air from which the plant derives its nourishment, death from starvation will soon follow.

130. There are other elements which are made use of by plants, but, as life may be prolonged without them, they are regarded as of secondary importance. In this list are Phosphorus, Calcium, Sodium, Magnesium, Chlorine, and Silicon.

131. The Compounds Used.—With the single exception of oxygen, the elementary constituents named above do not enter into the food of plants in an uncombined state; on the contrary, they are always absorbed in the condition of compounds, as water, carbon dioxide, and the

Nitrates		Ammonia.
Sulphates		Potash.
Carbonates	of	Lime.
Phosphates		Iron.
Silicates, or		Soda, or
Clorides		Magnesia.

Of the last the nitrates of potash and ammonia, sulphate of lime, carbonates of ammonia and lime, are probably to be considered as the most important for ordinary plants. Water is necessary for all plants, and carbon dioxide for those which are green.

132. In addition to the foregoing many organic compounds are absorbed in particular cases, as in those plants which live in decaying animal or vegetable matter (saprophytes), as well as those which absorb the juices from living plants (parasites).

133. Diffusion.—When absorbed, the solutions diffuse through the watery protoplasm and the watery contents of the vacuoles, "cell-sap." This diffusion continues from cell to cell in thin-walled tissues, and is here known as osmosis, the thin cell-walls serving as permeable membranes through which the solutions pass. In laboratory

experiments the rate of diffusion varies greatly, and is dependent upon (*a*) the solution itself, (*b*) the substance in which it diffuses, and (*c*) the temperature; thus hydrochloric acid diffuses more than twice as rapidly as common salt, and seven times as rapidly as cane-sugar. This law must hold for solutions in plants also.

134. Absorption of Gases.—Gases, also, are absorbed directly by living cells, and these are diffused through other gases in the plant, or they enter into watery solutions, as described above.

135. Assimilation.—In all the foregoing the plant is simply taking material, but the latter does not yet properly constitute a part of its living substance. It is still plant-food, and must undergo certain important chemical changes before it becomes a part of the plant itself. These chemical changes in the aggregate constitute Assimilation.

136. Carbon-assimilation.—The best-known assimilative processes are those by which the plant obtains its carbon, hence called carbon-assimilation. The first of these processes (*photosyntax* or *photosynthesis*) results in the formation of a carbohydrate, commonly starch ($C_6H_{10}O_5$) from carbon dioxide (CO_2) and water (H_2O), and to this the term assimilation has until recently been restricted. When a cell containing chloroplasts absorbs carbon dioxide, the latter unites with the water and forms carbonic acid (H_2CO_3), which is much more easily decomposed than either the carbon dioxide or the water. In sunlight (or any similar light of sufficient intensity) this carbonic acid is broken up by the protoplasm of the chloroplasts, and a new compound (probably formic aldehyde, CH_2O) is formed, while at the same time the excess of free oxygen (O_2) is given off. Now six molecules of CH_2O equal $C_6H_{12}O_6$, glucose or grape-

sugar, and a subtraction of a molecule of water (H_2O) yields the formula of starch ($C_6H_{10}O_5$). These changes may be expressed as follows:

$$CO_2 + H_2O = H_2CO_3 = CH_2O + (O_2, \text{ set free}),$$

and $$6(CH_2O) = C_6H_{12}O_6 = C_6H_{10}O_5 + H_2O.$$

Now while starch is probably not formed in such a direct way, it is worthy of note that in the chemical changes which take place between the absorption of carbon dioxide and the appearance of starch in the chloroplasts there is a setting free of oxygen precisely as required by the expression above. Moreover, in some cases the carbohydrate formed in photosyntax is not starch, but glucose, or even oil or other physiologically equivalent compounds. These carbohydrates are taken into the protoplasm as constituents of its substance, from which it may build a cellulose wall ($C_6H_{10}O_5$), or form glucose ($C_6H_{12}O_6$), sucrose ($C_{12}H_{22}O_{11}$), inulin, gums, oils, acids, etc. About one half of the dry substance of plants is carbon, all of which has been obtained from the carbon dioxide of the air by the process outlined above.

137. Nitrogen-assimilation.—Another important assimilative process is that by which nitrogen is obtained. This substance, although not present in such large quantity as carbon, is of high importance on account of its entering largely into the composition of protoplasm. Inasmuch as about 80 per cent of the air is free nitrogen, it might be supposed that plants derive it from this source, but careful experiments show this not to be the case. On the contrary, the nitrogen is derived from compounds in the air, soil, and water, chiefly in the form of nitrates of various bases (e.g., soda, potash, lime, ammonia, etc.), or some ammonia salt (e.g., the nitrate, chloride, sulphate,

carbonate, etc.). These are chiefly, if not entirely, absorbed by the roots, and in many plants the tubercles formed by parasitic organisms have been thought to aid in the process (Fig. 47). In the higher plants it has been shown that these compounds undergo decomposition and reconstruction in the leaf, the result being the formation of proteid substances; but it is also held that probably every living cell is capable of taking part in these processes.

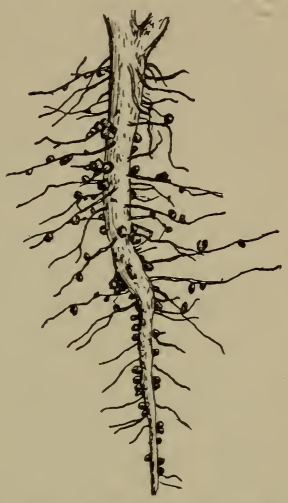


FIG. 47.—Root of Bean (Vicia) showing tubercles slightly reduced. (After Strasburger.)

138. Sulphur-assimilation.—Of the assimilation of sulphur still less is known than in the case of nitrogen. We know that sulphur is absorbed in the form of sulphates (of ammonia, potash, lime, and magnesia), and some of these are to be found in the cells of plants, but where and how they are broken up is not known. It has been suggested that the crystals of calcium oxalate which occur in many plants are residua of chemical changes by which sulphur was set free from calcium sulphate. If true, this would show that the assimilation of sulphur takes place in all active tissues of the plant.

139. Assimilation of other Substances.—Phosphorus is absorbed in the phosphate of lime, which undergoes decomposition in the tissues, but the details of the process are not known. A number of other substances—e.g., potassium, calcium, iron, etc.—enter into the proper food of plants as solutions of their salts, which afterwards undergo

decomposition, thus allowing their assimilation. They are commonly called the "ash" of plants, and are often erroneously regarded as consisting of unassimilated matter. That they enter into the vital activities of the plant has been shown by the experiment of withholding them, with the result that the plant so treated always languishes or dies.

140. Further Chemical Changes.—Even after the various substances which constitute plant-food have become assimilated they undergo many chemical changes. Every living tissue, and perhaps every living cell, is the seat of chemical changes in assimilated matter, whose results have in many cases been made out by chemists who have made numerous analyses, but in no case are the details of these chemical changes certainly known. We know that in many of these operations oxygen is absorbed by the active cells, and that as one result of their activity they excrete carbon dioxide. These after-changes of assimilated matter have been known in physiology as metastasis or metabolism.

141. Digestion and Use of Starch.—Among the most important of the subsequent chemical changes are those which render the starch in the chloroplasts soluble, allowing it to diffuse to other parts of the plant with great freedom. The nature of these changes appears to vary somewhat in different plants, but they consist essentially in the change of the insoluble starch into a chemically similar but soluble substance. Glucose ($C_6H_{12}O_6$), inulin ($C_6H_{10}O_5$), and cane-sugar ($C_{12}H_{22}O_{11}$) are the more common of the soluble substances so formed, and one or other of these may frequently be detected in the adjacent cells after the disappearance of the starch from the chlorophyll.

142. These diffusing carbohydrates are imbibed by the

protoplasm of the living tissues, and constitute its most important food. In connection with the nitrates and sulphates, etc., also imbibed, they furnished the materials for the increase of protoplasmic substance in growing cells.

143. The Storing of Reserve Material.—In many plants the surplus starch is stored up in one or more organs as reserve material; thus in the potato the starch formed in the leaves in sunlight is, in darkness, transformed into glucose, or a substance very nearly like it, and in this soluble form it is diffused throughout the plant, and in the underground stems (tubers) is again transformed into starch. So in the case of many seeds a mass of reserve material is stored up, generally in the form of starch (e.g., the cereal grains), and sometimes in the form of oily matters (e.g., the seeds of mustard, flax, castor-bean, squash, etc.).

144. The Use of Reserve Material.—In the use of reserve material, as in the germination of starchy seeds, the starch appears to undergo a change much like that in its disappearance from chlorophyll. Here it is certain that oxygen is absorbed, and that carbon dioxide is evolved, while the starch is transformed into glucose. Similar transformations doubtless take place in the use of the starch stored up in buds, twigs, stems, bulbs, etc.

145. In the germination of oily seeds, after the absorption of oxygen, starch is (in many cases, at least) first produced, and from this the soluble sugar is formed. In any case, after the solution is attained, the subsequent changes are similar to those which follow the transformation of the starch of the chlorophyll.

146. Alkaloids and Acids.—Among the most obscure of the subsequent chemical changes are those which give rise

to the alkaloids. These are compounds of carbon, hydrogen, nitrogen, and generally oxygen, as follows:

Nicotine ($C_{10}H_{14}N_2$), found in tobacco.
Cinchonia ($C_{20}H_{24}N_2O_2$), found in Peruvian bark.
Morphia ($C_{17}H_{19}NO_3$), found in the opium-poppy.
Strychnia ($C_{21}H_{22}N_2O_2$), found in the seeds of Strychnos.
Caffeine ($C_8H_{10}N_4O_2$), found in coffee and tea.

147. These and many others occur in plants in combination with organic acids, such as malic acid ($C_4H_6O_5$); tartaric acid ($C_4H_6O_6$); citric acid ($C_6H_8O_7$); oxalic acid ($C_2H_2O_4$); tannic acid ($C_{14}H_{10}O_9$). These acids are probably formed by the oxidation of some of the sugary or starchy substances in the plant, while the alkaloids with which they are combined appear to have some relation to the nitrogenous constituents of the protoplasm.

148. From the fact that the alkaloids are formed more abundantly in those tissues which have passed the period of their greatest activity, it may be surmised that they are either compounds of a lower grade than the ordinary albuminoids, or the first results of the incipient decay of the cells.

149. Results of Assimilation and Metabolism.—In the preceding paragraphs we have found that chlorophyll-bearing plants absorb carbon dioxide and exhale free oxygen, the former being decomposed in the chloroplasts in sunlight, and the oxygen being set free as a consequence. In other words, the absorption of carbon dioxide and the exhalation of oxygen are essential parts of the process of carbon-assimilation.

150. Now, it may be shown that oxygen is absorbed and carbon dioxide evolved, as results of certain metabolic processes which take place in any tissues, whether possessing chlorophyll or not, and independently of the presence

or absence of sunlight. In the sunlight the absorption of carbon dioxide in carbon-assimilation is so greatly in excess of its exhalation as a result of metabolism, that the latter is unnoticed. In darkness, however, when carbon-assimilation is stopped, the exhalation of carbon dioxide becomes quite evident.

151. So, too, with oxygen: in the sunlight its evolution from carbon-assimilation is so greatly in excess of its absorption (for metabolism) that the latter was long unknown; but in the absence of light its absorption becomes manifest. Parasites and saprophytes, as well as those parts of ordinary plants which are wanting in chlorophyll, as flowers and many fruits, deport themselves in this regard exactly as chlorophyll-bearing organs do in darkness.

152. Division of Labor.—In homogeneous-celled holophytes (i.e., green plants whose cells are all alike), whether few- or many-celled, every cell performs all the operations noted above; but in heterogeneous-celled holophytes there is a division of labor, some cells or masses of cells engaging in certain activities quite different from those engaged in by other cells or tissues.

153. Nutrition of Moss-like Plants.—In a moss the cells of the root-hairs (rhizoids) which clothe the subterranean part of the stem engage in the absorption of watery solutions almost exclusively, and since they do not take part in carbon assimilation they are destitute of chlorophyll. On the other hand, the cells in the leaves are active in carbon assimilation, and have an abundance of chlorophyll. They absorb carbon dioxide from the air and but very little, if any, water or soluble food-matter. The cells of the leaves and stem must therefore obtain their supply of watery solutions from the cells in the soil. The cells contiguous

to those which absorb the solutions from the soil absorb from the latter, those next removed now absorb from those newly supplied, and so on, from cell to cell, to those at the upper extremity of the plant. In this way, by simple absorption from cell to cell, water and solutions are transported to all portions of the plant-body. Now, many of the cells above ground are often in contact with dry air, into which some of their water evaporates. The cells which suffer this loss of water repair it by absorbing water from contiguous cells, and these absorb from still others, and so on. There is thus a general upward movement of water in the moss-stem due to the loss of water from the leaves. Again, it is seen that the carbohydrates are formed in the green cells alone, and from these they are diffused and absorbed as solutions from cell to cell throughout the plant. Thus there may be an upward movement of water while there is a downward diffusion of carbohydrates (and probably of other assimilated matters also).

154. Nutrition of Higher Plants.—In a plant with a still more complex structure, as, for example, the common sunflower, the cells of the surface of the roots absorb watery solutions, which are then absorbed from cell to cell in the large and numerous roots, finally passing in the same way, from cell to cell in the stem, and even to the leaves and flowers. The loss of water by evaporation from the leaves is much less, proportionately, than from the leaves of mosses, the latter consisting of but a single layer of unprotected cells; while the active cells in the sunflower-leaf are protected by a layer of specially modified thick-walled cells (the epidermis) less pervious to moisture. When, however, the stomata (breathing pores) are open for the ingress and egress of gases, much moisture escapes,

and this is replaced by absorption from cell to cell as in the mosses. The fact that moisture escapes through the open stomata has led to the assumption that they are for the purpose of permitting moisture to escape, and that the leaves of higher plants are "organs of evaporation." On the contrary, the stomata are clearly for preventing as far as possible the loss of water, while permitting the free interchange of gases, and the leaf is rather a skilfully devised structure in which a multitude of thin-walled cells gorged with moisture are exposed freely to the air with a minimum of loss of water by evaporation. The stomata of the leaves and stem when open admit the external gases to the intercellular spaces of the whole plant, and also allow the internal gases to escape into the air. There is thus a respiration in plants of the high organization of the sunflower, but when examined closely this does not differ in any essential from the simple absorption and excretion of gases by a single-celled plant.

155. Nutrition of Hysterophytes.—In the hysterophytes (parasites and saprophytes) the solutions absorbed consist partly or wholly of assimilated matter. When this includes the carbon products of assimilation the plant does not develop chlorophyll, as in the dodders, Indian-pipes, broom-rapes, and the vast assemblage of "fungi." When, however, there is little or no absorption of carbon compounds, chlorophyll is present and the leaves are well developed, as in the mistletoe. In the dodders the absorption is performed by suckers (outgrowths) on the stems, and as a consequence the roots do not develop. In these leafless, rootless, and eventually almost stemless plants there is probably little assimilation of any kind; they are nourished much as the flower- and fruit-clusters of ordinary

plants are. The evaporation of water is probably as rapid in hysterophytes as in holophytes of equal structural complexity and similar habits. The fungi quickly lose their water and become wilted and dried up when their supply of moisture is cut off. On the other hand, among the flowering hysterophytes the absence or small size of the leaves greatly reduces the amount of evaporation. Clearly, also, the respiration of hysterophytes is less than in holophytes, there being little or no absorption of carbon dioxide. Oxygen, however, is absorbed, and carbon dioxide excreted, by most if not all hysterophytes.

Practical Studies.—(*a*) Germinate seeds of cabbage or radish on moist cotton cloth, and examine the organs for the absorption of liquids (the roots), noting especially the root-hairs on their surface.

FIG. 48.—Showing method of making water-culture experiments.

(*b*) Germinate several kernels of Indian corn in moist sand, and when the roots are two to four centimetres long transfer the plants to wide-mouthed bottles or jars, supporting them as in Fig. 48. Fill one of the jars with pure (distilled) water; fill a second with well-water (which always contains many, if not all, of the materials of plant-food); fill a third with water from a stream or pond (which also always contains all, or nearly all, the materials of plant-food). Notice that the plants will grow in all the jars, as all are supplied with carbon dioxide and water, the most important plant-food; but the best and longest continued growth takes place in the second and third jars.

(*c*) In case the materials can be obtained, fill a fourth jar (as in the previous experiment) with a solution of the following constitution:

Distilled water.....	1000 cubic centimeters
Potassium nitrate.....	1.0 gram
Sodium chloride.....	0.5 "
Calcium phosphate.....	0.5 "
Calcium sulphate.....	0.5 "
Magnesium sulphate.....	0.5 "

With this solution perfect plants may be grown, if care be taken to renew the solution from time to time.

(*d*) Osmosis may be demonstrated as follows: tie a piece of fresh bladder securely across the mouth of a thistle-tube containing a strong solution of sugar, and invert it in a vessel containing pure water. The water will enter the thistle-tube, greatly increasing its height, while sugar will diffuse into the water.

(*e*) Pour enough water over dry beans to cover them, put in a warm place, and note the rapidity and amount of the absorption of the water.

(*f*) Place a quantity of fresh Pond Scum (Spirogyra) in a dish of water; expose it to the sunlight for some hours and then examine it for starch with the aid of the microscope, making use of the iodine test. When starch has certainly been found, put the dish in a dark (but not cool) chamber, and after some hours repeat the foregoing examination. No starch will now be found.

(*g*) Select two thrifty potato-plants of about equal size, and at the period of flowering, when the tubers are beginning to grow, cover one with a tight box or barrel, so as to shut off all the light and prevent starch-making. At the expiration of a fortnight examine and compare the tubers of the two plants.

(*h*) Put a dry apple-twig into a short piece of gas-pipe, closing the ends, not very tightly, with clay; put it into a fire and heat to redness. The carbon left will be of the form, and about half the weight of the dry twig.

(*i*) Examine the roots of clover for the minute tubercles (1 mm. in diameter) which have been thought to have something to do with the securing of nitrogen by the plant.

(*j*) Germinate a handful of Indian corn in moist clean sand, and, as the plants grow, taste the kernels from time to time. The sweet taste shows that the starch has changed into sugar for the nourishment of the growing plants.

(*k*) Cut off a stem of geranium and apply a bit of blue litmus-paper to the moist surface. The paper will turn red on account of the presence of an acid in the water of the cells.

(*l*) To show that CO_2 is exhaled by plants as a result of metabolism, place soaked beans in a tall cylinder, cover tightly, and keep for some hours in a warm room. Upon lowering a small lighted candle into the cylinder it will be extinguished by the CO_2.

(*m*) To demonstrate that green plants exhale CO_2 as a result of metabolism, place a leafy plant under a bell-jar which fits air-tight upon a glass plate. With the plant put a dish containing lime-water (caustic) or baryta-water. The whole is to be kept in a warm room for some hours in complete darkness, when the lime or baryta water will be turbid from the formation of a carbonate.

(*n*) Examine the vegetative filaments (organs of absorption) of

toadstools, mushrooms, and other large fungi, noting the absence of chlorophyll.

(*o*) Carefully remove a dodder (Cuscuta) from the plant upon which it is parasitic, and observe the suckers which penetrate the tissues of the host.

GROWTH.

156. Growth of the Cell.—A young cell consists of a nucleus and a solid (continuous) mass of cytoplasm closely invested by a wall. During the nutritive processes described above the substance of the cytoplasm is increased, and this requires an increase in the area of the wall; these two increments constitute the simple growth of the cell. Later, the absorption of water and the formation of a large vacuole, with or without an increase in the mass of the protoplasm, may require the increase in the area of the wall; this also is growth of the cell. In its increase in area the wall is first distended by the internal pressure and new matter (cellulose) is secreted upon or in it, thus permanently increasing its area.

157. Growth of the Plant-body.—In simple plants every cell may grow, producing an aggregate growth of the whole plant-body. As each cell reaches a certain size it divides into two, which then grow, and divide again, and so on. Continued growth thus involves the growth of the cells and their fission, and where the plant-body or the growing member is made up of similar cells growth takes place in all its parts. Where, however, the plant-body is made up of dissimilar cells, involving and implying dissimilarity of function, growth is sooner or later confined to particular masses of cells, occupying definite portions of the plant-body or its organs. In such cases growth is generally confined to the younger cell-masses, but it must be remembered also that some cell-masses have a short

growing period, while others retain their power of growth for long periods. The woody stem of an ordinary dicotyledonous shrub or tree, for example, consists of masses of different kinds of cells which soon lose their power of growth; thus the wood-cells, vessels, and even the parenchymatous cells of the wood, pith, and bark are soon incapable of growth in size, and retain but little longer the power of growth in thickness of the wall. In the same stem certain other cells (lying between the wood and bark, and commonly known as the cambiam) retain their growing power for many months, and it is these which enable the plant to increase its diameter year by year.

158. Growth in Length.—Since most cells have a limited period of growth it follows that in the growth of

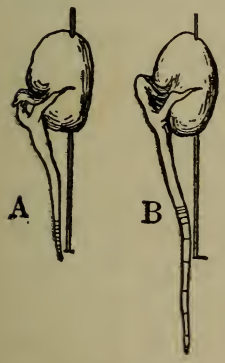


FIG. 49.

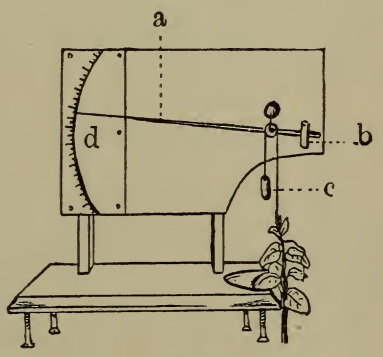


FIG. 50.

FIG. 49.—Growth of the root. *A*, root marked with India ink. *B*, the same root after further growth.

FIG. 50.—Instrument (auxanometer) for measuring growth of stems. *a*, a delicately constructed index balanced by the weight *b*; *c*, weight on thread which passes over the pulley to the plant; *d*, graduated arc: one-tenth natural size.

an axis each part retains its power of elongating for a short time only. In roots the elongation of cells and, as a consequence, of the root itself, is confined to the terminal portion (Fig. 49). Many stems retain their power of growth

in length for a greater time, so that each internode may grow after many others have formed above it. In such a case the lower internodes are the first to cease growing, and these are followed by those above in succession. The increase in the height of a plant is the aggregate growth of its internodes (Fig. 50).

Practical Studies.—(*a*) Make longitudinal sections of the tip of the root of Indian corn, or onion, and study in succession the cells of different ages, beginning at the growing point. Note the differences between the young cells near the growing point and the older ones at a distance from it.

(*b*) Make a cross-section of a young (green) stem and observe that all the cells are active in growth.

(*c*) Make a cross-section of a one-year-old twig of a dicotyledon (as apple, elm, or willow) and observe that the growing cells are confined to a narrow ring, the cambium, between the wood and bark.

(*d*) Study the growth of Indian-corn root by marking it at regular intervals with India ink.

(*e*) Measure the rate of growth (in length of stems) by means of an auxanometer (Fig. 50).

THE PHYSICS OF VEGETATION.

159. Since all parts of plants are composed of matter, it follows that they are subject to physical forces. In a living cell there is no suspension of the action of any force or of any physical law. Every atom of matter in the cell is as much under the control of force as it was before it entered into living matter. In each cell there are many active forces, and what we see is the resultant of all, not of one alone, and it is this complex result which sometimes has puzzled us. It is impossible at present to make a complete statement of all the physical activities in living plants; we may, however, study the behavior of the living cells, cell-masses, or the whole plant under the influence of physical forces of varying intensities.

160. Heat.—For every cell there is a certain range of temperature in which it is active, culminating in an *optimum* temperature; above this its activity decreases rapidly to its *maximum* temperature, where all activity ceases. In like manner below the optimum temperature activity decreases (not so rapidly, however) until the *minimum* is reached, where activity ceases again. This range of activity is not the same for all plants, and in many-celled plants it often differs considerably for different parts of the plant-body. Sachs determined this range for the germination of the following seeds:

	Minimum.	Optimum.	Maximum.
Indian Corn.	9° C. (= 48° F.)	34° C. (= 93° F.)	46° C. (= 115° F.)
Scarlet Bean	9° C. (= 48° F.)	34° C. (= 93° F.)	46° C. (= 115° F.)
Pumpkin. .	14° C (= 57° F.)	34° C. (= 93° F.)	46° C. (= 115° F.)
Wheat.....	5° C. (= 41° F.)	29° C. (= 84° F.)	42° C. (= 108° F.)
Barley.	5° C. (= 41° F.)	29° C. (= 84° F.)	37° C. (= 99° F.)

161. Common observation shows that plants differ much as to the degree of heat necessary for germination, as well as for other activities; but we have little in the way of careful measurements upon anything more than the germination of seeds. Certain experiments appear to indicate that the range in green parts of plants is much greater than has usually been supposed, in some cases approaching 0° C. and in others reaching 50° to 55° C. (122° to 131° F.), or even more.. On the other hand, it is certain that other parts of plants will not endure such temperatures; e.g., roots and underground stems.

For our ordinary terrestrial flowering plants the minimum temperature ranges from near 0° to about 10° C. (32° to 50° Fahr.), the maximum from about 35° to 50° C. (95°

to 122° Fahr.). The optimum varies so greatly that it is not possible to make a definite statement, some plants growing best at 10° C. (50° Fahr.), while others require from 25° to 35° C. (77° to 95° Fahr.) or even more.

162. When the maximum temperature for a plant-cell is exceeded, a point is soon reached where, by coagulation of the albuminoids or by some other changes the structure of the protoplasm is permanently altered, rendering all further activity impossible, even upon the return to a favorable temperature. Such a cell is "dead." The protoplasm has lost its power of imbibing water, and the cells consequently lose their turgidity. In watery tissues chemical changes at once begin, resulting in the rapid disintegration and decay of the substances in the cell. Those plants, or parts of plants, which contain the least water are capable of enduring higher temperatures than those which are more watery.

163. In many respects the results of too great a reduction of temperature are similar to those produced by too great an elevation. There is observed the same coagulation of the albuminoids, resulting in the destruction of the power of the protoplasm to imbibe water, and, as a consequence, in the loss of the turgidity of the cells. Moreover, as in the case of injury from high temperature, those cells which are the most watery are the ones which, other things being equal, are injured most quickly by a reduction of temperature.

164. Embryo plants in seeds, when dry, are able to endure almost any degree of low temperature; but after they have germinated, and the cells have become watery, they are generally killed by a reduction to, or a few degrees below, 0° Cent. (32° Fahr.). So, too, the comparatively

dry tissues of the winter buds and ripened stems of the native trees and shrubs in cold countries are rarely injured even in the severest winters, while the young leaves and shoots in the spring are often killed by slight frosts.

165. Death from low temperature is always accompanied by the formation of ice-crystals in the succulent tissues; these are formed from the water of the plant, which is abstracted from it in the process of congelation. Much of the water thus frozen is that which fills the cavities (vacuoles) of the cells, while some of it is that which moistens the protoplasm and cell-walls.

166. As the liquid in the vacuoles is not pure water, but a mixture of several solutions, it freezes at a lower temperature than water, and then, according to a well-known law of physics, separates into pure ice-crystals and a denser unfrozen solution. By a greater reduction of temperature more ice-crystals may be separated out and the remaining solution made denser still. This increasing density tends to retard the formation of ice-crystals, and it is probable that it is only in extremely low temperatures, if at all, that the liquids in the plant are completely solidified.

167. A plant which has been frozen may survive in many instances if thawed slowly, but if thawed quickly its vitality is generally destroyed. Thus many herbaceous plants will endure quite severe freezing if they are afterward covered so as to secure a slow rise of the temperature, and many bulbs, tubers, and roots will survive the severest winters if covered deeply enough to prevent sudden thawing. Likewise turgid tissues, which are not living, as those of many succulent fruits, are injured, or not, by freezing according as the thawing has been rapid or slow.

Practical Studies.—(*a*) Plant a few seeds of radish, barley, wheat,

and Indian corn in each of two flower-pots and place one of the pots in a cool cellar and the other in a warm room. Note differences in growth in the plants in each pot, and also compare growth of similar plants in the two pots.

(*b*) Observe the average daily temperature during the time that the hickory-trees are opening their buds in the spring. Compare this with the average temperature during the time of most vigorous development of the leaves and twigs, and also during the time of the development of the fruit.

(*c*) With a thermometer measure the temperature of the water of ponds and ditches when the earliest vegetation appears in the spring. This consists for the most part of diatoms, which form a brownish scum on the water or a brown coat on sticks and stones.

(*d*) Measure in like manner the temperature of cold springs in which vegetation is found.

(*e*) When Indian corn is producing its flowers (tassels and silk), observe the average temperature of the air and compare it with the temperature of the soil at the average depth of the roots.

(*f*) Enclose a small plant of Coleus (a common "foliage-plant") and a clover-plant in a tin pail, covering them loosely. Enclose also a thermometer. Set the pail in a tub of ice-water, allowing it to remain for an hour or two. Note the effect upon each plant. Or make the experiment by first growing little plants of wheat and pumpkin or squash, and using these. The wheat will survive; the pumpkin or squash will not.

Now make an experiment substituting hot water, and using a spring plant (as hepatica or anemone) and a summer plant (as Indian corn). Raise the temperature to 40° Cent. (104° Fahr.) and then increase the heat very slowly beyond this point. Notice effect upon each plant.

(*g*) In the autumn notice that some plants are killed by frosts which leave others unharmed.

(*h*) Thaw out two frozen apples, one in warm water rapidly, and the other in ice-water slowly. The first will be more injured, the second less.

168. Light.—Directly or indirectly all plants are dependent upon the light. Although many parasites and saprophytes grow in complete darkness, they do so by using material which developed in the light. We have seen (par. 136) that carbon-assimilation is possible in the light only in cells containing chlorophyll. All the carbon of

vegetation came originally from chlorophyll-bearing cells, made active by the light. Just how the light affects the chloroplasts in carbon-assimilation is not known, nor do we know how light brings about the formation of chlorophyll by the protoplasm. We can only regard light as a force which, acting upon the complex compound, protoplasm, produces molecular changes resulting in the secretion, first, of chlorophyll and, second, of a carbon compound. Here it must be remarked that not all cells secrete chlorophyll in the light, although many which are normally colorless become green under its influence; thus, while many roots and underground stems become green on exposure to the light, the petals of many flowers, the stems of the dodders, and the cells of fungi when so exposed develop no chlorophyll. It is a fact, however, that some kind of coloring-matter is produced in nearly all cells on exposure to the light, as is well shown by the familiar experiment of growing flowers, fruits, and various fungi in complete darkness, when they are usually much paler or wholly wanting in color. The color of some flowers appears to be independent of the direct action of light, as shown by Sachs, who obtained perfectly normal flowers of the tulip, iris, squash, and morning-glory when grown in the darkness, although the leaves were completely etiolated.

169. Light appears to be essential to plants only as enabling them to assimilate carbon; therefore those which get their carbohydrates from others can live in total darkness. Thus many saprophytes (i.e., plants which live upon dead or decaying vegetable matter) are found in dark cellars, caves, mines, etc., growing to full size and maturing their fruits perfectly. So, too, some parasites (i.e.,

plants living upon and getting their food from living plants) grow in darkness, feeding upon the inner tissues of their hosts (supporting plants) where little or no light penetrates.

170.—It has been shown by experiment that light somewhat retards the growth of certain cells. A shoot grown in darkness or deficient light is always longer than one grown in strong light; but, on the contrary, the leaves on such stems are small and poorly developed. Even in the daily growth of plants the rate during the day is less than during the night. This has been called by Vines the "tonic influence of light." Here we must note that while the stem grows more rapidly in darkness, the leaves grow less rapidly, and in complete darkness remain very small.

Practical Studies.—(*a*) Place a plant in the light for a few hours, and then examine the tissues of its leaves, testing by iodine for starch. Place a similar plant in total darkness for 10 to 12 hours and make a similar test.

(*b*) Place a fresh white potato in the sunlight for a few days, and examine thin sections of its tissues for chlorophyll.

(*c*) Put a green plant in complete darkness for a few days, and note the disappearance of its chlorophyll.

(*d*) Examine a well-blanched leaf of celery; only leucoplasts will be found.

(*e*) Examine the white, red, blue, purple or yellow petals of flowers; no chlorophyll will be found, although the flowers may have been in full sunlight.

(*f*) Examine the tissues of toadstools and other fungi, (*a*) grown in darkness and (*b*) in the light; no chlorophyll will be found in either.

(*g*) Make sections of the stems of dodder (Cuscuta), and note the absence of chlorophyll.

(*h*) Look for moulds and other fungi in dark cellars, as examples of saprophytic plants which have grown without the direct aid of light.

(*i*) Cover the end (30 to 40 centimeters) of a cucumber-plant, bearing young flower-buds, with a tight box, so as to exclude all light. Notice that the flowers develop perfectly as to size and color although

in total darkness, while the leaves are small and lacking in normal color.

(*j*) Cover in like manner a portion of a cucumber-plant bearing very young fruit. Notice that the fruit develops in darkness as well —in size, at least—as in the light.

(*k*) Grow some seedlings in full light and others in darkness, and note that the latter are the longer.

(*l*) Use an auxanometer (Fig. 50) for measuring the growth of plants, and compare the day growth with the night growth.

171. Gravitation.—Many cells always grow in a particular direction with respect to the earth's mass. Thus the principal roots usually grow toward the earth, while most stems grow away from it. When a seed germinates, its roots invariably take a downward and its stems an upward direction, and it does this regardless of its immediate surroundings. This is well illustrated in the experiment shown in Fig. 51, in which the stems invariably grow upward, deeper and deeper into the ground and darkness, while the roots grow down, out of the ground, and into

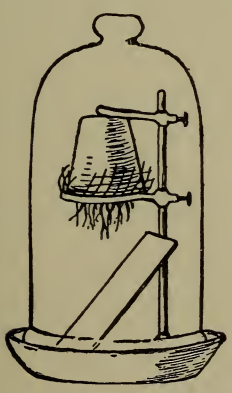


FIG. 51.

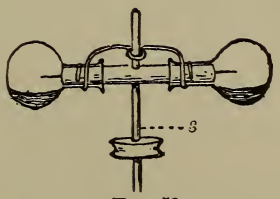


FIG. 52.

FIG. 51.—Inverted flower-pot under a bell-jar. One tenth natural size.
FIG. 52.—Rotating apparatus. *s*, steel rod bearing a pulley by means of which it is rotated. One fifth natural size.

the light. Experiments show that centrifugal force acts precisely like gravitation. If we rotate a growing seed

rapidly (Figs. 52, 53, 54) the roots grow outward in the direction of the centrifugal force, and the stems grow inward, or in opposition to that force. With a slower horizontal rotation (Figs. 52, 53) both roots and stems

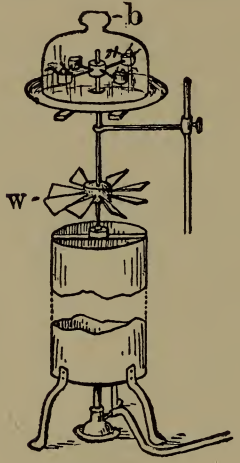


FIG. 53.

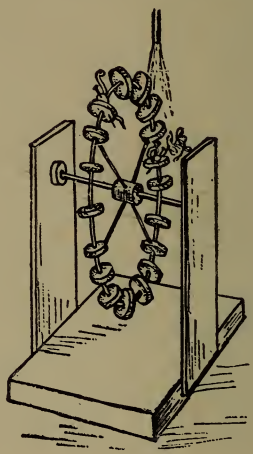


FIG. 54.

FIG. 53.—Rotating apparatus driven by the hot air from a gas-jet. One tenth natural size.
FIG. 54.—Rotating wheel driven by a jet of water.

grow diagonally, the angle depending upon the rate of revolution, but in vertical rotation the direction is not changed.

172. In considering the mode of action of gravitation upon parts of plants we cannot suppose that the root-cells are more subject to it than the cells of the stem. The theory which affords the most satisfactory explanation assumes that each cell exhibits what may be called "polarity" with respect to the lines of constant force (gravitation, or centrifugal force). When these lines are vertical, as in the case of gravitation, the cells exhibit vertical polarity; when the lines of force are horizontal, the cells, as a consequence, arrange themselves horizontally; and

when, as in the experiments above (Figs. 52, 53), there are two lines of force acting at right angles to each other, the axis of polarity is diagonal, and the cells assume a diagonal position.

173. The action of the plant in response to such forces is known as Geotropism (see par. 186) and careful study has shown that it is by no means confined to vertical stems and roots. Many stems grow as persistently in a horizontal as ordinary ones do in a vertical direction. So, also, many roots grow almost at right angles to the controlling force (gravitation, or centrifugal force).

Practical Studies.—(*a*) Plant seeds half an inch deep in a flower-pot (Fig. 51), cover with coarse netting, and invert upon a ring-stand. Below it place a mirror, standing at a proper angle to reflect light upon the under surface of the flower-pot. Place a tall bell-jar over the apparatus and keep water in the dish, so as to preserve a moist atmosphere. Now place the whole in a light room of the proper temperature. Upon germination the roots will appear below, while the stems will grow upward into the soil.

(*b*) Slip two small flasks containing a little water over opposite ends of a wooden rod and retain them in place by a coil of wire, as shown in Fig. 52. A sprouted seed is previously fastened to each end of the rod by a stout pin, and the whole is then rotated rapidly upon the steel rods by a water or electric motor Note the direction of the roots and stems.

(*c*) Construct the rotating apparatus shown in Fig. 53. Upon a knitting-needle fasten a cork, in which are placed diagonally eight or ten strips of mica (*w*); near its upper end fasten a second cork, and cover with a bell-jar (*b*); support the needle upon the centre of a 10-cm. tube (4 in.) which is 60 to 100 cm. long (2 to 3 ft.). Fasten seeds to the upper cork by pins, and place a Bunsen burner under the tube to rotate the wheel.

(*d*) Construct a rotating wheel (Fig. 54), using a knitting-needle for the axis, and a brass wire on which are strung corks for a rim. Attach the seeds to the corks by pins, and place it under a fine jet of water.

(*e*) Put plants in various unusual attitudes in a dark room, and observe the positions assumed by the leaves and stems.

(*f*) Germinate beans, and after the radicles have protruded a cen-

timetre or two fasten the seeds in such a way (under a bell-jar) that the radicles point directly upwards. Observe that the roots soon begin bending towards the earth.

174. Electricity.—While plants exhibit electrical conditions in common with other material objects, they seem at present to possess no physiological significance. Every chemical change in the cell probably produces some disturbance of its electrical conditions and of those of its neighboring cells. So, too, the considerable amount of evaporation of water from leaves and other aërial parts probably produces electrical disturbances. Various observers have noticed weak electrical currents between different tissues upon making transverse sections of stems or leaves. None of these appear to be of any importance physiologically, at least as now understood. Strong electrical currents, especially when interrupted, quickly disorganize the protoplasm; weak currents retard or arrest protoplasmic movements, and very weak currents produce no perceptible effect.

175. Humidity of the Air.—The walls of living plant-cells are usually permeable to water, and when exposed to relatively dry air they lose a portion of their watery contents by evaporation. In many-celled plants this loss is repaired by the absorption of water from contiguous cells not so exposed, and the latter in turn repair their loss by absorption from the surrounding moisture (water or moist earth). The condition of the atmosphere may thus set up many disturbances in the plant.

176. Since evaporation of water takes place so generally in our common plants, it has been sometimes supposed to be one of the necessary activities of the plant, and is spoken of as Transpiration. It is, however, a purely physical

phenomenon, though not a simple one. It must not be forgotten that the water in plant-cells contains many substances in solution, and consequently evaporates less rapidly than pure water, in accordance with well-known physical laws. Moreover, the attraction of the substance of the cell-walls for the water counteracts, to some extent, the tendency to evaporation; and in the same manner, even to a greater extent, the water is prevented from passing off by the "imbibition power" of protoplasm. It is, in fact, impossible to deprive cellulose and protoplasm of all their water in dry air at ordinary temperatures.

177. In submerged aquatics there is of course no loss of water by evaporation; it is only in aërial plants or parts of plants that such a water-loss occurs. In the latter the exposed parts are protected against the dry air by the epidermal layer of cells, nearly impervious to water. Moreover, those plants which are exposed to drier air have a thicker epidermis, while in those living in moist air the epidermis is always thinner. These facts show that evaporation of water is not necessary to the life of the plant, and that, on the contrary, the loss of water is carefully guarded against.

178. The breathing-pores of the green and succulent parts of higher plants, when open for the ingress and egress of gases, permit the escape of some moisture. They are placed over intercellular spaces, and these are in communication with the intercellular passages of the plant, which are filled with moist air and gases. Now, when the breathing-pores are open, these gases expand and contract with every change of temperature or atmospheric pressure, thus permitting the escape of considerable amounts of water; when, on the other hand, the breathing-pores are closed,

little or no escape of moisture is possible. The fact that the breathing-pores open and close, and that they are open when the conditions of the air favor less evaporation, and closed under opposite conditions, indicates that their function in respect to evaporation is to prevent or check it.

179. The Amount of Evaporation.—The conditions controlling evaporation are thus seen to be many and various. They never, or but very rarely, act singly, two or more of them usually acting together with varying intensity, so that the problem of the amount of evaporation taking place at any particular time is a complex and difficult one. All the observations yet made, and which have necessarily been upon a very small scale, indicate that the rate of evaporation is relatively very slow.

180. A given area of leaf-surface will evaporate much less water than an equal area of water-surface. The amount of the former has been estimated at from one seventeenth to one third of the latter, varying of course in different plants. A grape-leaf has been found to evaporate in twelve hours of daylight an amount of water equal to a film covering the leaf .13mm. (.005 in.) deep; a cabbage-leaf for the same time, .31 mm. (.012 in.); an apple-leaf, .25 mm. (.01 in.). An oak-tree was found to have evaporated in one season, during the time it was covered with foliage, an amount of water equal to a layer 33 mm. (about $1\frac{1}{3}$ in.) deep over all its leaf-surface. When we remember that the usual evaporation from a water-surface for the same period is from 500 to 600 or more milimeters (20 to 25 in.) we must conclude that leaves, instead of being organs for increasing evaporation, are able to successfully resist evaporation.

Supplementary Notes on the Movement of Water in the Plant.

I. *The Movement of Water in the Plant.*—It is clear, from what has been said, that in many-celled plants there must be a considerable movement of water in some parts to supply the loss by evaporation. Thus in trees there must be a movement of water through the roots, stems, and branches to the leaves, to replace the loss in the latter. This is so evident that it scarcely needs demonstration; it can, however, be shown by cutting off a leafy shoot at a time when evaporation is rapid; in a short time the leaves wither and become dried up, unless the cut portion of the shoot be placed in a vessel of water; in the latter case the water will pass rapidly into the shoot, and the leaves will retain their normal condition. If in such an experiment a colored watery solution (as of the juice of Poke-berries) be used instead of pure water, it will be seen that the liquid has passed more abundantly through certain tracts than through others, indicating that the tissues are not equally good as conductors of watery solutions.

II. *Path of Movement.*—As would readily be surmised, the tissues in ordinary plants which appear to be the best conductors are those composed of elongated wood-cells, and it is doubtless through them that the greater part of the water passes; furthermore, it is probable that the movement of the water is mainly through the substance of the cell-walls.

III. *Rapidity of Movement.*—The rapidity of the upward movement of water varies greatly in different plants and under different conditions. In a silver-poplar a rate of 23 cm. (9 in.) an hour has been observed; in a cherry-laurel 101 cm. (40 in.); and in a sunflower 22 metres (72 feet).

IV. *No Circulation of Sap.*—While there is an upward movement of the water in plants because of the evaporation from the leaves, there is no downward movement, as has been popularly supposed. The "circulation of the sap," in the sense that there is an upward stream in one portion of the plant and a corresponding downward stream in another, does not exist. Likewise, the belief still held by some people that in the autumn or early winter "the sap goes down into the roots," and that "it rises" in the spring, is entirely erroneous. There is actually more water (sap) in an ordinary deciduous tree in the winter than there is in the spring or summer (excluding, of course, the new and very watery growths).

V. *The Flow of Water* (sap) from the stems and branches of certain trees, notably from the sugar-maple, appears to be due to the quick alternate expansion and contraction of the air and other gases in the tissues from the quick changes of temperature. The water is forced

out of openings in the stem when the temperature suddenly rises; when the temperature suddenly falls, as at night, there is a suction of water or air into the stem. When the temperature is nearly uniform, whether in winter or summer, there is no flow of sap.

VI. *Root-Pressure.*—Here may be noticed what is called "root-pressure," which, though not connected with the air humidity, has some relation to the movement of water in the plant. If the root of a vigorously growing plant be cut off near the surface of the ground and a glass tube attached to its upper end, the water of the root will be forced out, often to a considerable height. Hales, more than a hundred and fifty years ago, observed a pressure upon a mercurial gauge equal to 11 meters (36.5 ft.) of water when attached to the root of a vine (Vitis). Clark (1873), in a similar manner, found the pressure from a root of a birch (Betula lutea) to be equal to 25.8 metres (84.7 ft.) of water. This root-pressure appears to be greatest when the evaporation from the leaves is least; in fact, if the experiment is made while evaporation is very active, there is always for a while a considerable absorption of water by the cut end of the root, due probably, to the fact that the cell-walls had been to a certain extent robbed of their water by the evaporation from above. Root-pressure is probably a purely physical phenomenon, due to a kind of endosmotic action taking place in the root-cells.

Practical Studies.—(*a*). Collect a quantity of green grass in the middle of the day when it is not wet; weigh it accurately, then thoroughly dry it in an oven, being careful not to scorch it. Weigh again: the difference in the two weighings will be approximately the amount of water in the living plant, although some water will still be left in the plant by ordinary drying.

(*b*) Weigh a handful of beans; put them into warm water or moist earth for a day or two until they are beginning to sprout. Then gather them up carefully, wipe off all external dirt and moisture, and weigh again. Here the difference will be approximately the amount of water absorbed by the protoplasm.

(*c*) Place some specimens of Green Slime or Pond Scum on a dry glass slip, using no cover-glass. Note with the microscope the rapid evaporation of water as shown by the collapsing of the cells.

(*d*) Gather fresh leaves of clover; suspend some of them under a bell-jar or inverted tumbler which stands in a plate containing a little water. Put the other leaves into a dry plate with no protection from the dry air. Note that the evaporation is very much more rapid in the dry air than in the moist air under the bell-jar.

(*e*) Strip off the epidermis from a leaf (hyacinth, live-for-ever, etc., are good) and note that the evaporation is much greater (as shown

by the more rapid wilting) than from the uninjured leaf. This shows that the epidermis and its breathing-pores retard evaporation.

(*f*) Lilac-leaves have breathing pores upon their lower surfaces alone. Provide two leaves: cover the lower surface of one with a thin coat of varnish, which will prevent evaporation through the breathing-pores; suspend both in a current of dry air, and note that the one not varnished withers sooner than the other. Make the varnish by heating together equal parts of beeswax and lard.

(*g*) Cotton-wood leaves have breathing-pores upon both surfaces. Repeat experiment above (*f*).

(*h*) Procure a well-grown geranium (20 to 25 cm. high) in a flower-pot. Cover the pot with a piece of thin sheet-rubber, tying it around the stem of the plant. Insert a short tube (provided with a cork) at the proper place, through which to introduce water. Weigh the whole at intervals of a few hours. The loss will be the amount of evaporation (approximately). By adding weighed quantities of water at intervals the experiment may be continued indefinitely.

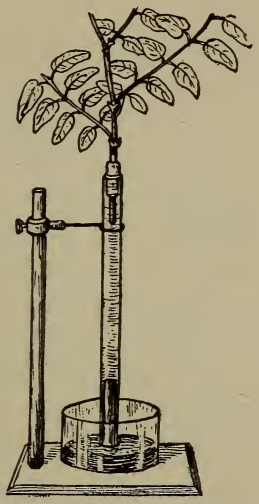


FIG. 55.—Experiment showing the force with which water enters the plant. One sixth natural size.

(*i*) Cut off a rapidly growing leafy shoot of the apple or geranium and place the lower end in a bottle of water. Close the bottle by pressing soft wax into the mouth of the bottle around the stem. On account of the upward movement of the water through the shoot its level in the bottle will be perceptibly lowered. This will be more evident the smaller the diameter of the bottle.

(*j*) Make the experiment shown in Fig. 55 by fastening a leafy shoot air-tight in the upper end of a glass tube; invert and fill with water, and place in a cup of mercury. The water loss by evaporation will be replaced by water absorbed with such force as to raise the mercury in the tube.

(*k*) Cut off a small branch of a maple-tree on a cold winter day; bring it into a warm room. As soon as the temperature of the branch rises, the sap (water) will begin to flow from the cut surface. Lower the temperature and the flow will cease; raise it again and the flow will be resumed.

(*l*) Cut off the stem of a rapidly growing sunflower a couple of nches above the ground; slip over it the end of a tightly fitting

india-rubber tube 8 to 10 cm. long. Slip into the other end a small glass tube 5 to 10 mm. in diameter, being sure to make the joints water-tight. The "root-pressure" will cause the water to rise into the verticle tube. Note the effect of a change of temperature of the soil.

181. Supply of Energy to the Plant.—The work done by a plant involves the expenditure of energy. In hysterophytes the decomposition of the chemical compounds absorbed by them affords a supply of energy fully or nearly adequate for all their needs. In holophytes the case is far different; they absorb compounds of simple chemical constitution supplying relatively little available energy, but in their chlorophyll-stained cells they are able to arrest the energy of the sunbeam, and divert it to the work of the plant. Doubtless green plants derive some energy from the decomposition of the compounds absorbed by them and perhaps more from the heat to which they are exposed, and possibly to a slight extent from other sources, but the great supply of energy is the light of the sun. It has been shown experimentally that any other bright light, whether produced by lamps of various kinds or by the electric arc, when of sufficient intensity, may be a source of energy for green plants.

PLANT MOVEMENTS.

182. Living Things Move.—It is one of the essential characteristics of living things that they move, although "motility" and "life" are not synonymous. A complete examination of the motility of plants would include the many kinds of movements exhibited by protoplasm, whether naked (as in zoöspores) or enclosed within walls of greater or less rigidity, and in addition the very slow movements connected with growth and nutrition. These

movements, which are all referable to the activities of protoplasm, may be grouped under the following heads, viz.: Nutation (or Automatism), Geotropism, Heliotropism and Irritability.

183. Nutation.—Under this term are gathered those cases in which terminal parts of plants move spontaneously and somewhat regularly in definite directions. It has been observed that the growing ends of climbing plants perform circular nutations; thus in the hop and honeysuckle the free ends of the stems rotate in the direction of the hands of a watch (Fig. 56*a*), while in the yam, bean, and morning-glory the rotation is the reverse (Fig. 56*b*). In other cases the nutation is a simple swaying back and forth, as in many leaves and growing shoots.

FIG. 56.—Twining stems—*a*, of hop; *b*, of yam.

184. Mr. Darwin has shown that as soon as a seed germinates the little root at once begins a sort of revolving motion, its tip describing more or less elliptical or circular figures. By this circumnutation a root is enabled to find those places in the soil which offer the least resistance to its passage. Moreover, it has been shown that the tip of the root is sensitive to pressure, and when it comes in contact with any object bends from it. In this way the root-tip guides the advancing root through the interstices of the soil, avoiding on every hand the pebbles and harder bits of earth. The root-tip appears also to be sensitive to

moisture, bending towards that side which is most moist, and thus in a dry soil the roots are constantly guided into those parts where the moisture is most favorable.

185. Not only is the root-tip endowed with the power of circumnutation, but, in the words of Mr. Darwin, "All the parts or organs in every plant whilst they continue to grow are continually circumnutating. If we look, for instance, at a great acacia-tree, we may feel assured that every one of the innumerable growing shoots is constantly describing small ellipses, as is each petiole, sub-petiole, and leaflet. The flower-peduncles are likewise continually circumnutating; and if we could look beneath the ground and our eyes had the power of a microscope, we should see the tip of each rootlet endeavoring to sweep small ellipses or circles, as far as the pressure of the surrounding earth permitted. All this astonishing amount of movement has been going on year after year since the time when, as a seedling, the tree first emerged from the ground."

Practical Studies.—(*a*) Soak a few beans in water, and when the little roots begin to protrude pin the beans carefully to a weighted cork under a bell-jar, and observe the movements of the radicles.

(*b*) Germinate and study in like manner the seeds of cabbage, radish, Indian corn.

(*c*) Fix a slender filament of glass to the rapidly growing end of a shoot of fuchsia, geranium, or verbena (using a drop of thick shellac-glue), and observe the circumnutation. If a plate of glass be laid horizontally just above the tip of the glass pointer, the movements of the latter may be readily recorded by lines or dots on the glass. Or a microscope may be fixed in such a position that the tip of the pointer is in focus, when the movement will be made visible to the eye.

(*d*) Fix a glass pointer to the tip of a leaf of a suitable plant (as a fuchsia, geranium, primrose, etc., grown in a pot) and record the nutations on a glass plate fixed vertically or horizontally in such a way as to be approximately at right angles to the pointer.

186. Geotropism.—Under this is included all those movements of plants or their parts due directly or indi-

rectly to gravitation (paragraphs 171 to 173). The movement toward the earth is termed geotropism, and organs exhibiting it are said to be geotropic. Organs which move away from the earth, then, exhibit negative geotropism, and are said to be negatively geotropic.

Practical Studies. Here refer again to the experiments on page 99 under the topic "Gravitation."

187. Heliotropism.—In like manner the movements of plants or their parts due to the light are included under the term heliotropism. Organs which turn toward the light are heliotropic (or sometimes positively heliotropic), while those which turn away from it are said to be negatively heliotropic, and the phenomenon is negative heliotropism. The upper surface of most leaves is positively and the lower negatively heliotropic; yet some leaves have both surfaces positively heliotropic, and their blades are therefore approximately vertical and parallel with the meridian, as is notably the case in the compass-plant (*Silphium laciniatum*) of the prairies of the United States. The tendrils of many plants are negatively heliotropic, as are also the runners of some others.

188. The movements of plants with the decrease in the amount of light, as at nightfall, often called the "sleep of plants," (nyctitropism) are heliotropic in their nature. Some of these are quite marked, as in many of the clovers, beans, peas, and their allies. The species of Oxalis are notable for these movements.

189. In regard to the sleep of plants, observation has shown that at night the cotyledons of many plants take a different position from that which they have during the day. In the cabbage and radish, for example, the cotyledons stand during the day almost at right angles to the

stem, but at night they rise and are parallel to one another. Seedlings of parsley, celery, tomato, and four-o'clock behave in a similar manner. In some cases the cotyledons, instead of rising, at night, bend abruptly downwards. This happens with seedlings of certain kinds of sorrel (Oxalis), although curiously in other species of the same genus the cotyledons rise.

190. The leaves of many (if not all) plants assume a position at night more or less different from that which they have during the day. In the common purslane the leaves at night bend upwards in such a manner as to lie more nearly parallel with the stem. In wood-sorrel (Oxalis) the leaflets bend abruptly downward and closely surround the common leaf-stalk. In clover, on the contrary, the leaflets bend upwards, afterwards folding over to one side. In beans the leaflets sink down somewhat after the manner of the wood-sorrel. In some cassias and the sensitive-plants the nocturnal position differs remarkably from that of the day; not only are the leaflets folded, but the leaf-stalks change their position, in some cases rising and in others becoming sharply depressed. Even some conifers have been observed to show a well-marked sleeping state at night, and it is very likely that when we study them attentively very few of the higher plants will be found which are wanting in this power. The familiar closing of certain flowers at night and opening again in the morning, and the exactly reversed action, are to be regarded as of the same nature as the nyctitropic action of leaves.

Practical Studies.—(*a*) Grow a nasturtium (Tropæolum) in a window, noting carefully the rapid bending of its leaves toward the light.

(*b*) Select a symmetrically grown fuchsia, place it in a window, and note the rapidity with which the leaves and stems turn toward the light.

(*c*) Germinate various seeds in a window, and observe the heliotropism of the seedlings. Young beet seedlings are very sensitive.

(*d*) Grow a strawberry-geranium (Saxifraga sarmentosa) in a hanging-basket or pot in a window, and observe that the dependent runners bend away from the light.

(*e*) Germinate seeds of cabbage, radish, parsley, or tomato, and note carefully the position of the cotyledons during the day and night.

(*f*) Observe the sleeping state of wood-sorrel (Oxalis), clover, and purslane. Then make careful notes of diurnal and nocturnal positions of the leaves of as many plants as possible. Where it is possible to do so it is recommended that photographs be taken of the waking and sleeping states of plants. Careful sketches, at least, should be made.

191. Irritability.—Many parts of plants exhibit movements as a result of physical contact with some object. For this sensitiveness to contact the term irritability has been used. One of the best examples of this is the well-known "sensitive-plant" (*Mimosa pudica*, Fig. 189) whose leaflets quickly assume a particular position when rudely touched. A more remarkable example is the Venus's fly-trap (*Dionæa muscipula*, Fig. 169), in which each lobe of the leaf has three sensitive hairs upon its upper surface; and when these are touched the two halves of the leaf close together quickly. Many stamens are sensitive to touch, as in the barberry, portulaca, and purslane.

192. The tendrils of many plants exhibit irritability, and when touched by an object bend toward and eventually coil around it. If after contact and some bending the tendril be freed once more, it will soon straighten out as before, and may be made to bend in the opposite direction by another contact; and this may be repeated a number of times.

Practical Studies.—(*a*) Grow a few sensitive-plants in pots for

study of irritability. Seeds may be procured at any seed-store for a few cents, and are easily grown in a warm room.

(*b*) Rub one side of a squash tendril gently with a pencil for a few seconds, and observe that it soon begins to curve; then rub the opposite side and notice that the curvature is reversed.

(*c*) Place a stick in contact with a tendril, and watch the coiling of the latter around the former.

(*d*) Watch the coiling and subsequent spiral twisting of the tendrils of the grape.

REPRODUCTION.

193. Purpose.—The structure and physiology of every plant point to and culminate in its reproduction. Reproduction is thus the highest of plant functions. Through it the species is perpetuated; through it variations of the species are continued; through it the fittest survive generation after generation. Philosophically speaking, reproduction is a device in nature whereby new individuals arise from older ones, so that the world is constantly filled with younger organisms to replace those which are old and worn out.

194. In Single-celled Plants every cell is capable of producing new plants. The same is true of some few-celled plants. Reproduction is here one of the functions of every cell. With the increase in complexity of the plant body, this function is more and more restricted to certain cells and aggregations of cells. We can thus speak of reproductive cells, as distinct from vegetative cells, and finally of the reproductive organs, in contrast with the vegetative organs of the plant.

195. Asexual Reproduction.—Broadly speaking, there are two general ways by which plants are reproduced. In the first a cell, or a mass of cells, may become detached, and grow into a new plant, as in the common cases of the production and development of zoöspores in many aquatic

plants, of conidia among fungi, and of brood-cells and brood-masses (gemmæ) among liverworts and mosses. The case is essentially the same where true buds, and even branches separate from the parent plant, as the "bulblets" in the axils of the leaves of some lilies, and in the inflorescences of some onions, the runners of strawberries, the trailing runner-like stems of buffalo-grass, the tubers of many plants, as the potato, and perhaps the spontaneously-deciduous twigs of cottonwoods and some willows. In all these cases the essential feature is the separation from the parent plant of one or more living cells, which continue to grow, eventually producing a plant like the parent. We go but a step further when we purposely cut off portions of plants, which are then grown as "cuttings" by being placed in moist earth. Even in the familiar operations of grafting and budding, where the severed part is grown in the tissues of another plant, the operation is essentially one of asexual reproduction.

196. Sexual Reproduction.—In marked contrast to the foregoing are the various modifications of the sexual reproductive process in which the essential feature is the union of two cells (gametes) in the formation of the first cell of the new plant. In the simplest cases two apparently similar cells fuse into one, but as we pass to higher plants there is an increasing difference between the cells concerned. Moreover, while in the simpler cases the fusion appears to involve the whole of each cell, in the higher plants it is confined to the nuclei.

197. Of Isogamy and Heterogamy.—Upon a close examination of sexual reproduction we find that in the classes Chlorophyceæ and Phæophyceæ (see Chapter VIII), the gametes may be alike in size and other obvious characters

(isogamous), or they may be unlike in size and otherwise quite different also (heterogamous). Thus, all except the highest Protococcoideæ, all of the Conjugatæ, all but the higher Siphoneæ and Confervoideæ of the first-mentioned class and nearly all of the second class are isogamous. The families Vaucheriaceæ, Saprolegniaceæ, and Peronosporaceæ (of the order Siphoneæ) and Sphæropleaceæ Cylindrocapsaceæ and Œdogomaceæ (of the order Confervoideæ) are heterogamous. Among the Phæophyceæ, the Fucoideæ alone are heterogamous. In all classes above the Chlorophyceæ and Phæophyceæ heterogamy is the invariable rule.

198. Results of Cell Union.—As we pass from the lower plants to the higher, there is an increasing complexity in the results of the cell union. In the Chlorophyceæ and Phæophyceæ the result is a single egg-like cell (oöspore) which sooner or later develops into one or more new plants. In passing to the Coleochætaceæ and Florideæ, we find that in the former the single spore soon becomes invested with a cellular layer of protective tissue, and the spore itself upon germination becomes several-celled. In the Florideæ the fertilized cell not only divides early, but each segment emits a branch whose end segment becomes detached as a spore, and in the meantime the whole has become invested by a layer of protective tissue. In the Charophyceæ the growth of the protective tissue precedes fertilization, so that from a protective device which only *follows* fertilization, we have now the same device developing before fertilization, and serving as a protection to the unfertilized cell. In bryophytes and pteridophytes we recognize in the archegone the homologue of the structure just referred to in the Charophyceæ; in fact it is difficult to separate the latter from the former by any absolute char-

acters. The results of fertilization, however, are of a greater degree of complexity in the bryophytes and pteridophytes than in the Charophyceæ; while in the latter the result is a singe spore, in bryophytes it is a cylindrical many-celled axis the upper portion of which develops spores by the division of internal cells, and in the pteridophytes it is an axis terminating in roots below, and bearing leaves above. There is a noticeable immersion of the archegone in the tissues of the parent plant in the pteridophytes, and in the gymnosperms there is a complete submergence. At the same time, in the gymnosperms, with the retention of the macrospore within the sporangium (nucellus), and the development of one or two nucellar integuments, there is a still greater increase in the protective tissue surrounding the oöspore. This is carried a step further in the angiosperms where the leaf (carpel) folds over and encloses the coated nucellus (ovule). The results of fertilization in gymnosperms and angiosperms (effected here by the pollen-tube) are little if any higher than in the pteridophytes, consisting in the development of an embryo plant with its root, stem, and leaves. The protective tissues surrounding the embryo, especially those of the seed-coats, are, however, notable additions, made necessary by the fact that the embryo is still to be separated from the parent plant.

199. Increased Parental Care.—When we take a comprehensive view of sexual reproduction, we note that as we pass from the lower plants to the higher, there is step by step an increase in the amount of aid given by the parent plant to the new organism. Additional protective devices appear, and the period of parental care is more and more prolonged in successively higher classes. In illustration of this we may contrast the naked resting-spore of a pond

scum (Spirogyra) with the triply-protected, vigorous embryo plant of the sunflower. In the former the new plant must begin life for itself with but one cell, while in the latter it is cared for by the parent plant until it has developed a myriad of cells.

CHAPTER VI.

CLASSIFICATION AND DISTRIBUTION.

200. General Principles of Classification.—We may now proceed to take a hasty survey of the Plant Kingdom, studying here and there a selected example which must serve to illustrate the structure of a considerable group. In such a study of plants it is better to begin with the simpler and more easily understood forms, and to pass from these to those which are structurally more complex and whose functions are correspondingly complicated.

201. On account of the vast number of species of plants —there are now known about 175,000, and the whole number in the world is probably more than twice as many—it is necessary for us to group them in such a way as to bring together those which resemble one another. In such grouping we take into consideration as many things as possible, and those plants which are alike or similar in the greatest number of particulars are considered to be more nearly related to each other than those with fewer points of resemblance. Moreover, it has been found that resemblances in structure are of far greater importance than resemblances in habits. Two plants, for example, may be parasitic in habit, and yet their structural differences may be so great as to warrant us in placing them in entirely different groups.

202. If we bring together all the plants of the Vegetable Kingdom, we may recognize pretty easily six large groups, all the members of which show more or less of resemblance to each other. These are the Branches. Likewise, if we consider the plants in each Branch, we may make several groups, each of which will include those with still greater resemblances. These groups are Classes.

203. In like manner Classes are divisible into Orders; Orders into Families; Families into Genera; Genera into Species. Each Species is composed of individual plants, all of which bear a close resemblance to each other. In some Species there is such a variation in the individuals composing it that they are grouped into Varieties.

204. Applying the foregoing, we have the following as the classification of the common Sunflower:

Kingdom of Plants.
Branch, Anthophyta.
Class, Angiospermæ.
Order, Inferæ.
Sub-order, Asterales.
Family, Compositæ.
Genus, Helianthus.
Species, annuus.

205. It is necessary now and then to form sub-groups; thus Classes are often separated into two or more Sub-classes; so Orders are sometimes separated into Sub-orders; Families are frequently divided into Tribes and these again into Sub-tribes. So, too, a Genus may be divided into Sub-genera.

206. These various groups are very differently related to each other; in some cases several in succession form a regularly ascending series, but very commonly several groups are divergent from an initial point. This is well shown in

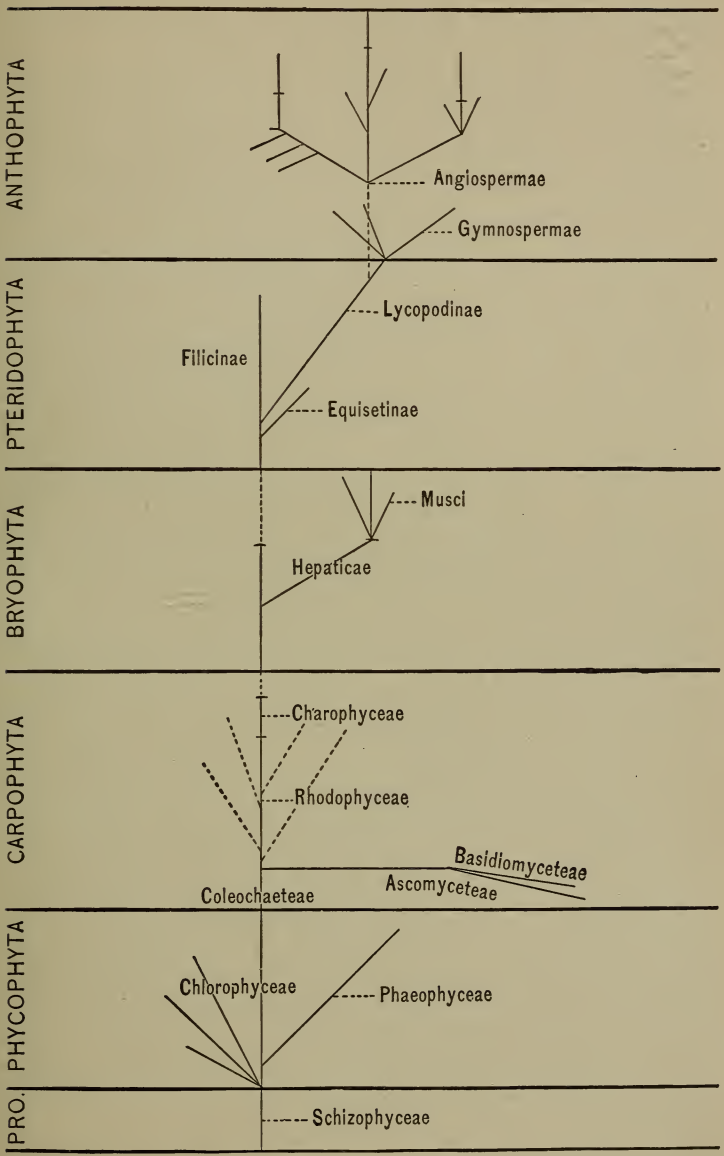


FIG. 57.—Chart showing relationship of the Branches and Classes.

the accompanying diagram (Fig. 57), which represents a "genealogical tree" of the Vegetable Kingdom.

207. In the study of plants we now begin with the simplest kinds, and pass to those which are more complex. It follows from what has been said above that in enumerating the groups of plants in the subsequent pages of this book we are often compelled when we reach the end of one group to return again to the common point of origin.

208. Geographical Distribution of Plants.—Plants are distributed widely over the surface of the earth. They are most abundant in the hotter climates, and decrease in number toward the poles. Likewise, they are more abundant upon the lowlands than upon the tops of high mountains. The regularity and amount of rainfall has also a controlling influence upon land vegetation, while for marine forms the direction and temperature of the ocean currents largely determine their distribution.

209. In general, we may say that light, temperature, and moisture are the chief controlling agents. Where these are favorable, vegetation is abundant; where they are unfavorable, vegetation is scanty or wanting. The cold and poorly lighted polar regions (VI and VI′ of the map), the cold mountain-summits, the dry deserts of Africa and Australia (IX and IX′), and the dark depths of the oceans are alike deficient in vegetation.

210. In general, similar conditions have brought about similar vegetations. The North American Forest Region (I) of the Western Hemisphere has its counterpart in the Europæo-Siberian Forest Region (I′) of the east, in which approximately similar conditions prevail. So, too, the Prairie Region of North America (II) is to be compared with the Steppe Region of Asia (II′), the Pampas Region

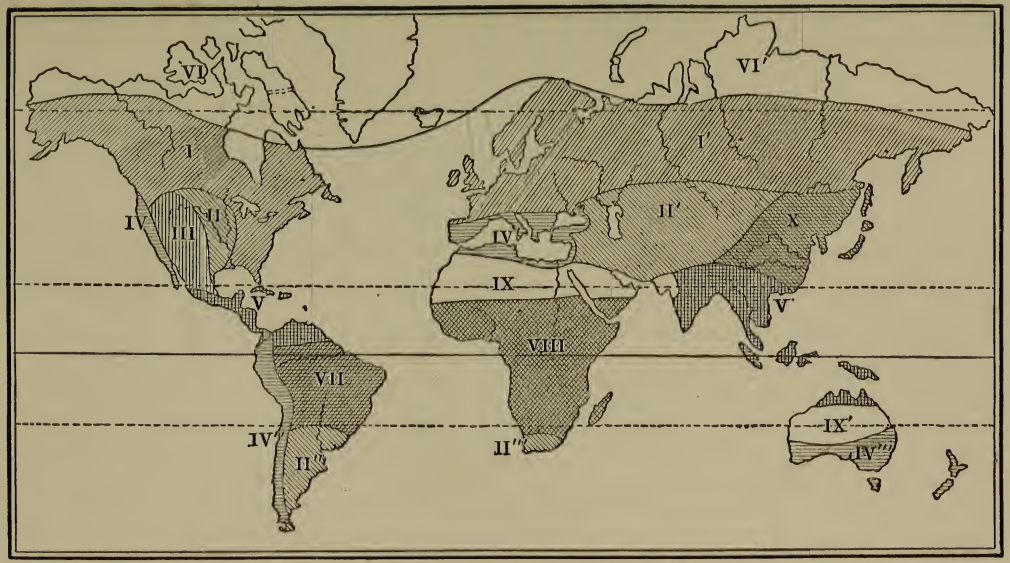


FIG. 58. I, North American Forest Region. I′, Europæo-Siberian Forest Region. II, Prairie Region. II′, Steppe Region. II″, Pampas Region. II‴, South African Region. III, Rocky Mountain Region. IV, California Region. IV′, Mediterranean Region. IV″, Chile-Andean Region. IV‴, South Australian Region. V, Central American or West Indian Region. V′, East Indian Region. VI, Arctic Region. VII, Brazilian Region. VIII, Central African Region. IX, Sahara Region. IX′, Australian Desert Region. X, Chino-Japanese Region.

of South America (II″), and the South African Region (II‴). The Californian Region (IV) is in many respects similar to the Mediterranean Region (IV′) and the Chile-Andean Region of South America (IV″).

211. The accompanying map (Fig. 58) shows one of the ways of dividing the earth into botanical regions. Each region is capable of subdivision into *districts*. The plants of a region or district constitute a *flora;* thus we may speak of the Prairie Flora, or the flora of the Upper Mississippi district, or the flora of Iowa.

212. Distribution of Plants in Time.—Most plants are short-lived. By far the greater number perish in a year or two, as is the case with our annuals and biennials. Some shrubs and trees may live for a considerable number of years, but even the most enduring generally die in a few centuries. The plants of the world are thus constantly dying off, and are as constantly being renewed. In the past ages of the world death and renewal occurred as in the present. Occasionally in the past the dying off in a particular species was more rapid than the appearance of new plants, with the result that the species eventually became extinct: many such cases are known to palæontologists. On the other hand, it has frequently happened that new forms have appeared as the older ones have died off, so that the character of a particular flora has thereby been gradually changed.

213. By a study of the fossil plants of any period in the world's history we may learn that the flora of each region has undergone great changes. The flora of North America in the Tertiary period was very different from what it is now, while the Cretaceous flora was still more unlike that of the present. Plants that now are confined to the east-

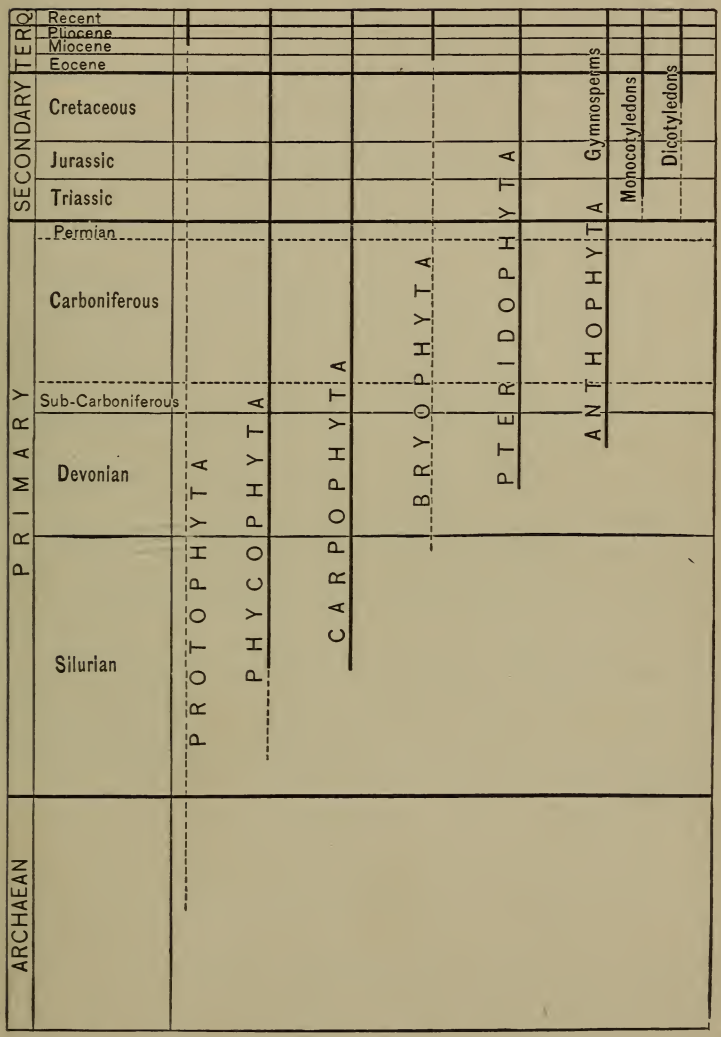


FIG. 59.—Chart showing distribution of plants in geological times. (The heavy lines show known, and the dotted lines probable, distribution.)

ern continent were then common in many parts of this continent, and tropical or sub-tropical species flourished abundantly in Nebraska and Dakota.

214. Moreover, we learn by such a study that many of the plants of the present were not yet in existence in certain geological periods. As we go back in geological time the vegetation is less and less like that of to-day. Thus the higher flowering plants (Dicotyledons) were not in existence earlier than the Cretaceous period, while the Lilies and their relatives date back to the Triassic. The great Carboniferous vegetation, from which our coal was derived, contained no plants with true flowers. There were no grasses or sedges, no lilies or orchids, no roses or violets, no oaks or maples. There were cone-bearing trees and tree-ferns, as well as gigantic club-mosses and horsetails; but even these were very different from any now living.

215. The foregoing table (Fig. 59) will show the main facts as to the distribution of the principal branches of the Vegetable Kingdom in geological time. It must be remembered that the geological record is as yet only fragmentary, and in all probability many of the lines will be carried down much further as our knowledge becomes more complete.

CHAPTER VII.

BRANCH I. PROTOPHYTA.

THE WATER-SLIMES, OR SEXLESS PLANTS.

216. The protophytes are the lowest and simplest plants, and they are often so minute as to require the highest powers of the microscope for their study. For the most part the cells are poorly developed; the protoplasm is frequently destitute of granular contents; and the nucleus is wanting or poorly defined in many cases.

217. The cells in all cases cohere little, if at all; and even when they are united into loose masses each one retains nearly as much independence as in the single-celled forms.

218. No sexual organs are known. The common mode of reproduction is by the fission of cells, although internal cell-division occurs also.

219. Most protophytes live in water and get their food from the solutions it contains. Some are blue-green or brown-green, and so are able to use carbon dioxide, while others are destitute of a green color and are parasites or saprophytes.

220. This branch contains the single class SCHIZOPHYCEÆ, the Fission Algæ, of about 1000 species, separable into two orders as follows:

Plants strictly one-celled..... Order 1, CYSTIPHORÆ
Plants few- to many-celled, forming threads. Order 2, NEMATOGENEÆ

ORDER 1. **CYSTIPHORÆ.** THE BLUE-GREEN SLIMES.

221. These are the lowest and simplest of plants; they live as single cells in the water, or they may be aggregated into slimy films on sticks and stones. There is but one family, *Chroöcoccaceæ,* represented by minute species of Chroöcoccus, Glœocapsa (Fig. 60), and other genera. Each cell divides into two, and these soon divide again, and so on. In Glœocapsa the cell-wall is much swollen into a jelly-like mass.

ORDER 2. **NEMATOGENEÆ.** THE NOSTOCS, ETC.

222. In the Nostocs and their near relatives (Oscillaria) there is a little coherence of the cells into chains or filaments. The cells form by fission, but after formation adhere somewhat to each other. The Nostocs (Fig. 61, *A*) occur in water or on moist ground as jelly-like masses of filaments. Some are amber-colored, some brownish, some bluish green. The species of Oscillaria (Fig. 61, *B*) are

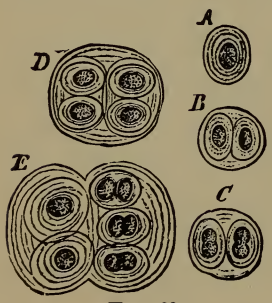


FIG. 60.

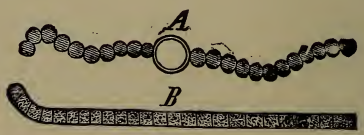


FIG. 61.

FIG. 60.—Cells of Glœocapsa in different stages of growth, showing division and the mode in which the daughter-cells are surrounded and enclosed by the gelatinous walls of the mother-cells. *A*, youngest stage; *E*, oldest stage. Magnified 300 times.

FIG. 61.—*A*, filament of Nostoc; *B*, end of filament of Oscillaria. Magnified 300 times.

mostly dark-green filaments collected into felt-like masses floating on the surface of the water, or growing on wet

earth or the wet sides of watering-troughs, etc. A peculiarity of these plants is their power of oscillating from side to side, while at the same time they move forward. In this manner they are enabled to travel considerable distances.

223. In Rivularia the filaments are generally arranged radially in little rounded masses. One of these (Rivularia fluitans) is often very abundant in lakes and slow streams, the little floating greenish balls being a millimetre or less in diameter. Other species occur as green slimy masses, as large as pin-heads, on the stones and stems of water-plants in ponds and brooks.

Practical Studies.—(*a*) Scrape off a little of the greenish slimy matter from a damp wall, mounting it in water; examine under a high power. Some small blue-green or smoky-green cells will be found belonging to the Blue-green Slimes (Chroöcoccus, etc.); of these some will probably be found in process of fission. Larger bright-green cells filled with granular protoplasm will also be found; these are a species of Protococcus (par. 236).

(*b*) In midsummer look along the water-line of fresh-water lakes and ponds for soft, amber-colored, rounded masses from the size of a pea to that of a hickory-nut. By mounting a small slice of one of these it will be seen under the microscope to be composed of myriads of filaments of Nostoc similar to *A*, Fig. 61. Occasionally a filament may be seen with a larger cell (a heterocyst), as in the figure. Its function is not known.

(*c*) Secure a handful of the dark-green filamentous growth which is common on the wet sides of watering-troughs, and place it in a dish of water. If an Oscillaria (Fig. 61, *B*), it will rapidly disperse itself, an hour being long enough to show quite a change in position. Now mount a few filaments in water and examine under a high power. They will be seen to sway from side to side, and to move quite rapidly across the field of the microscope.

(*d*) In midsummer scrape off one of the small jelly-like masses of Rivularia, so common on the submerged stems of water-plants; mount in water, crushing or cutting the mass so as to show the individual filaments. Each filament tapers from the centre of the mass outward, and at its larger end there is generally a large cell (a heterocyst).

Systematic Literature.—Wolle, Fresh-water Algæ of the United States, 235–335. Flora of Nebraska, 1. 15–25, *pl. 1–3*.

224. The Bacteria.—Some of the Fission Algæ have become much degenerated through being parasitic or saprophytic. They are still smaller than those already described, and are colorless. Their minute cells in some cases measure no more than .0005 mm. ($\frac{1}{50000}$ inch) in diameter. They are in some species rounded in shape, in others elongated like little rods, or in others more or less curved (Fig. 62).

FIG. 62.—Forms of Bacteria. *a*, Micrococcus; *b*, Bacterium termo (resting stage); *c*, Bacterium lineola; *d*, Bacillus ulna; *e*, Vibrio rugula; *f*, Spirochæte plicatile; *g*, Spirillum volutans. Magnified 650 times.

They are frequently provided with one or two cilia (i.e., whip-like projections of protoplasm), by means of which they move about with great activity.

225. Bacteria are found in great numbers in the watery parts of decaying organic matter, causing various kinds of fermentation. They reproduce by fission and spores with such astonishing rapidity that in a short time they swarm

in any exposed substance which is capable of furnishing them with food. Some of the species live in the watery juices of plants and animals, causing various diseases.

226. Some bacteria can endure high temperatures, and frequently appear in tightly closed vessels whose contents have been boiled. Some people have been led to explain their appearance under such circumstances by "spontaneous generation;" but thus far the facts are capable of other explanation.

227. The proper spores of bacteria (*endospores*) are produced singly within the cells. By the breaking of the filaments into their component cells other reproductive bodies (*arthrospores*) are formed.

228. On account of their minuteness, bacteria may be picked up by currents of air and borne long distances, and in this way they are doubtless often carried from place to place. When a pool of putrid water dries up, the bacteria with which it swarmed are blown away with the dust and dirt, dropping everywhere into pools, upon plants and animals living and dead, and even entering our lungs with the air we breathe.

The Bacteria (Bacteriaceæ) are here treated as one of the families of the Nematogeneæ, but they should rather be treated as degenerated species and genera of Oscillariaceæ and Nostocaceæ. Among those of especial interest to us are the following:

1. The bacterium of small-pox (Streptococcus variolæ), composed of minute globular cells, is now accepted as the cause of small-pox. That found in vaccine virus is a cultivated state, while that in small-pox is its virulent state.

2. The bacterium of ordinary putrefaction (Bacterium termo, Fig. 62, *b*) is composed of oblong cells. It is the cause or accompaniment of all ordinary decay of animal and vegetable substances.

3. The bacterium of apple-blight (Bacillus amylovorus) is the cause of a troublesome disease of apple-trees.

4. The bacterium of anthrax (Bacillus anthracis) is composed of

cylindrical cells, which are motionless. It occurs in the blood of animals suffering from anthrax.

5. The bacterium of consumption (Bacillus tuberculosis), of very slender cylindrical, motionless cells, has recently been shown to occur in the lungs and air-passages of consumptive patients.

6. The bacterium of leprosy (Bacillus lepræ), of cells similar to the preceding, but larger, is found in the tissues of those afflicted with leprosy.

7. The bacterium of diphtheria (Bacillus diptheriæ), somewhat similar to the preceding, is present in the false membranes in the pharynx in diphtheria.

Practical Studies.—(*a*) Put a pinch of cut hay or any other similar vegetable substance into a glass of water; keep in a warm room for a couple of days, or until it becomes turbid (from the abundance of bacteria); examine a minute drop with the highest powers of the microscope for active bacteria.

(*b*) Put a bit of fresh meat into water, and study the bacteria which will appear in it. Spiral forms like *g*, Fig. 62, may often be found in such a preparation.

(*c*) Examine the juices of decaying fruits.

Systematic Literature.—Grove, Bacteria and Yeast Fungi. Saccardo, Sylloge Fungorum **8**.

APPENDIX TO PROTOPHYTA.

The "Slime-moulds" (Mycetozoa).

A. **Their Place among Living Things.**—These organisms have commonly been regarded as plants, and in former editions of this book they were treated as protophytes. De Bary long ago placed them "under the name of Mycetozoa outside the limits of the Vegetable Kingdom," and this opinion as to their position is now shared by many biologists. They show no close affinity to any groups in the Vegetable Kingdom, but possibly may have some relationship to the bacteria. It may be that the Mycetozoa have descended from the bacteria, by a still further degeneration from the normal structure of the Schizophyceæ. Should this suggestion prove true, we might still question their right to a place in the Vegetable Kingdom, since they have departed so widely from the normal plant-structure. They are taken up here as organisms outside of the Vegetable Kingdom, but near to its lower limits, but the student is warned not to regard them as plants.

B. **Structure.**—A Slime-mould is a mass of naked, shapeless protoplasm (Fig. 63) during all the growing part of its life. In some species it is no larger than a pin-head, while in others it is as large

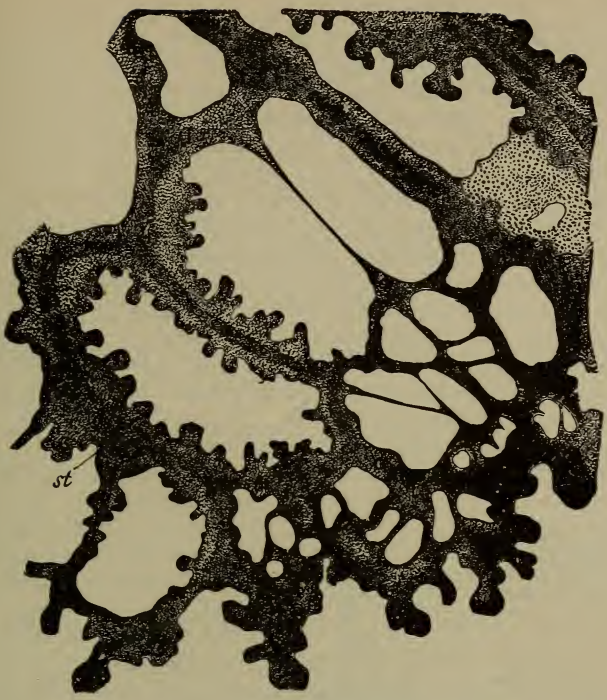


FIG. 63.—A part of a Slime-Mould (Physarum leucopus) in its motile stage. Magnified 350 times.

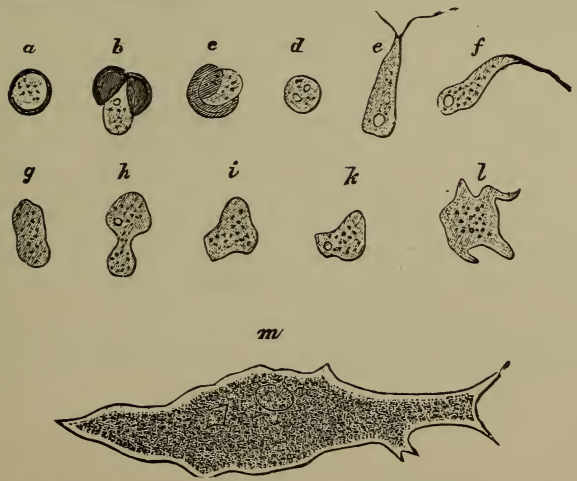


FIG. 64.—Early stages of a Slime-mould (Fuligo varians). *a*, a spore; *b*, *c*, the same, bursting the cell-wall; *d* to *l*, various stages; *m*, young Slime-mould.

as a man's hand. This mass of protoplasm, known as the plasmodium, is often yellow or orange-red in color, and is never green. It possesses to an extraordinary degree the power of moving itself from place to place. Slime-moulds obtain their food by absorbing solutions of decaying matter, and even engulf solid substances in the same manner as the Amœba.

C. **Spore-formation.**—When they have become full grown, they lose a good deal of their moisture, and the protoplasm then separates itself into a great number of minute rounded balls, each of which forms a cell-wall around itself. These little balls (spores) are thus nothing but bits of protoplasm securely covered. They may now be blown hither and thither without harm, and when at last they fall into a moist warm place they imbibe water, burst their coats, and are free naked masses of protoplasm again, thus completing the round of life (Fig. 64).

D. In its spore-bearing stage each Slime-mould is covered with a membrane (*peridium*), while internally it forms (1) spores, and (2) sometimes a filamentous framework (*capillitium*). In this stage its form is either (1) irregular in shape, resembling a dried plasmodium (then called a *plasmodiocarp*), or it is (2) a *sporangium* of uniform and regular shape (Fig. 65, *a*, *b*, *c*, *d*).

FIG. 65.—Several forms of the spore-bearing stage of Slime-moulds. *a*, Badhamia, × 20; *b*, Reticularia, × ½; *c*, Physarum, × 20, *d*, Stemonitis, natural size.

E. About 400 species of Slime-moulds have been recognized. They have been classified almost entirely upon characters derived from their spore-bearing stage. Many species occur in all parts of the United States, and may be readily found on the bark of trees, decaying logs, stumps, decaying mosses, etc., and on the bark-covered ground in tanyards. A fine large one—Fuligo varians—is especially common in tanyards, on manure-piles, and in and upon decaying planks of sidewalks.

Systematic Literature.—Massee, Monograph of the Myxogastres. Lister, Monograph of the Mycetozoa. Saccardo, Sylloge Fungorum 7[1].

CHAPTER VIII.

BRANCH II. PHYCOPHYTA.

THE SPORE-TANGLES.

229. This is an assemblage of quite diverse plants, ranging from minute unicellular species, on the one hand, to large seaweeds of considerable complexity, on the other.

230. In this branch we find the first examples of undoubted sexuality, that is, the production of new plants as a result of the union of two masses of protoplasm. In the simpler cases there is no appreciable difference as to form, size, color, origin, etc., between the uniting cells (*gametes*), but in the higher ones the gametes differ greatly. The immediate result of the union of the two sexual cells is the production of a new cell, the resting spore, zygospore, or oöspore, possessing very different characteristics from either. While the sexual cells have only ordinary walls, or none at all, the resting spores are covered with thick, firm walls.

231. The resting spore is so called because under certain circumstances it remains quiescent, while retaining its vitality, often for long periods of time. Thus at the close of the growing season, as upon the advent of the summer drought, or of winter, the resting spores fall to the bottom of the pools (in the fresh-water forms), and in the dried or frozen mud remain uninjured until the return of favorable conditions, when they germinate and give rise to a new generation of plants.

232. Nearly all the plants of this group contain chloro-

phyll, those of but five or six families being destitute of it. The green forms are all aquatic, and inhabit either fresh or salt waters. Those which have no chlorophyll are partly saprophytes, living upon dead organic matter, while others are parasitic, living upon and at the expense of living plants and animals: they are doubtless to be regarded as modified forms of some of the types of the chlorophyll-bearing portion of the group.

233. There are two classes of phycophytes, distinguished as follows:

Chlorophyll-green one-celled or filamentous plants, rarely composed of a plate of cells,..... Class 2, CHLOROPHYCEÆ
Olive-green filamentous or massive plants, the latter with rhizoids, Class 3, PHÆOPHYCEÆ

CLASS 2. CHLOROPHYCEÆ. THE GREEN ALGÆ.

234. These are typically green plants, containing ordinary chlorophyll in their chloroplasts. In the simpler cases they are one-celled, but typically they are composed of simple or branched filaments, while in a few cases they consist of a plate of cells. They are usually small or even microscopic plants, rarely exceeding a few centimetres in extent. For the most part they inhabit fresh waters, and as a consequence they are commonly called the Fresh-water Algæ. The parasites and saprophytes of the group are chlorophyll-less, and usually much degenerated.

235. This class contains about 7000 species, distributed among four orders, as follows:

Plant unicellular, gametes mostly equal and motile, Order 3, PROTOCOCCOIDEÆ
Plant unicellular, or an unbranched cellular filament, gametes equal, not motile,..... .....Order 4, CONJUGATÆ
Plant tubular, branched, gametes equal and motile, or unequal, Order 5, SIPHONEÆ
Plant a cellular filament, gametes equal and motile, or unequal, Order 6, CONFERVOIDEÆ

ORDER 3. **PROTOCOCCOIDEÆ.** THE GREEN SLIMES.

236. Common Green Slime may be taken as the representative of this order. It consists of minute, globular, green cells, and is to be found as a thin green layer on damp walls and rocks and the sides of flower-pots in greenhouses and conservatories, and in wet weather on wooden walks and the roofs and sides of houses. Green Slimes are commonly known under the name of Protococcus, although species of other genera are more common.

237. They reproduce asexually by fission, each cell dividing into two, and also by the formation of zoöspores which swim about for a time, after which they form a cell-wall and develop into new plants. The zoöspores of some Green Slimes unite sexually and produce resting spores.

238. One kind of Green Slime (Hæmatococcus lacustris) is the noted Red-snow Plant, which in the high north latitudes often covers the snow, giving it a reddish color. It also occurs on the mountain-tops in lower latitudes. Although really a green plant, its color is reddish in one of its stages.

FIG. 66.—Green Slimes, magnified. *a*, Protococcus; *b*, Scenedesmus; *c*, Pediastrum.

239. Related to the foregoing are the curious little lunate plants (species of Scenedesmus) which always lie side by side in fours, and the somewhat similar species of Pediastrum, consisting of a flat colony of 4 to 64 angular and loosely aggregated cells.

240. The Water-net (Hydrodictyon) is one of the most curious of the common plants of pools and slow streams in midsummer. Well-grown specimens are from 20 to 30 centimetres long (8 to 12 inches), and consist of an actual net made of cylindrical cells joined at their ends. The

whole net is a colony of plants, each of which reproduces by the formation of zoöspores: the latter after a time arrange themselves in the form of a net. New colonies are formed also directly by the protoplasm of a cell first breaking up into a great number of small ones (by internal cell-formation), these soon arrangeing themselves into a miniature net inside of the old cell-wall. The old wall eventually decays and sets free the new colony.

241. The Pond-scum Parasites.—There are many parasitic Green Slimes (of the family Chytridiaceæ) which live in the cells of plants and animals. They are minute chlorophyll-less cells, which eventually break up into zoöspores. They are common in cells of pond-scums (Spirogyra, etc.), diatoms, desmids, and other aquatic plants. A few species of the *Gall-fungi* (Synchytrium) occur in the aerial leaves of higher plants, forming rust-like spots, consisting of cells from which zoöspores will eventually escape.

Practical Studies.—(*a*) Scrape off a little of the green, paint-like coating from a flower-pot, a damp wall, or a sidewalk plank, and examine under a high power for common Green Slime (Protococcus, etc.).

(*b*) Examine the green plants collected from ponds and ditches for Scenedesmus and Pediastrum. The former may often be found in great numbers on the sides of glass jars or aquaria containing pond-plants.

(*c*) In midsummer search quiet pools for water-nets. With a fine scissors cut out a piece of one and mount carefully in water. Study with a low power of the microscope. Some of the cells will be found producing zoöspores. Search for young nets forming within the old cells.

(*d*) Carefully examine the cells of pond-scums, diatoms, desmids, etc., for Pond-scum Parasites (Chytridiaceæ). They may be recognized as spherical or flask-shaped colorless bodies within the cells. They are usually most abundant in water which has been standing for some time.

(*e*) Gall-fungi may be found upon the leaves of Evening Primroses,

Plantains, Mints, and some leguminous plants. In the study of these minute plants consult vol. i., part iv. of Rabenhorst's Kryptogamen-Flora, 1892.

Systematic Literature.—Wolle, Freshwater Algæ of the United States, 156–204. Saccardo, Sylloge Fungorum, **7**[1]. Flora of Nebraska, **1**, 29–35. *pl. 4.*

APPENDIX TO PROTOCOCCOIDEÆ.

The two organisms described below are usually regarded as plants, but they have little in common with plants aside from their green color. In all probability they, with a few near relatives, must eventually be placed outside the limits of the Vegetable Kingdom.

A. **Pandorina** is the pretty name given to a common fresh-water organism. It consists of a globular colony of green cells; each cell is provided with two cilia, which project outward from the ball, and by rapid vibration give it a rotary motion (Fig. 67). At a certain stage of its development some of the cells of the colony escape and swim about in the water; finally two come in contact with one another and unite, forming a resting spore (*E, F, G, H,* Fig. 67).

FIG. 67.—*A*, a colony of Pandorina morum; *C*, sexual cells escaping; *E*, *F*, *G*, union of sexual cells; *H*, resting spore. All highly magnified.

After a period of rest, the resting spore bursts its wall, the protoplasm escapes, and swims about for a time by means of two cilia with which it is provided; at last it comes to rest and divides itself into sixteen cells, which then constitute a new colony similar to that with which we started (*A*, Fig. 67).

B. **Volvox.**—The little spherical Volvox (Fig. 68) of the pools and

ditches is somewhat higher in structure than Pandorina, which it resembles in many respects. Volvox is a colony of very many little cells, each of which projects its two cilia outward, giving the ball a hairy appearance. By the lashing of the cilia the ball rolls about in the water. At a certain stage some of the cells enlarge and slip into the interior of the colony, becoming free oöspheres, each containing one germ-cell. At the same time other cells break up their protoplasm into motile antherozoids, which escape into the same cavity of the colony. At length the antherozoids unite with the oöspheres, when as a result the latter secrete thick walls, and thus become resting spores. Upon germination each resting spore divides its protoplasm into several hundred small cells, which then arrange themselves into a new colony. The asexual reproduction takes place by certain cells breaking into great numbers of little cells, which then unite themselves directly into a new colony in the interior of the parent colony (Fig. 68).

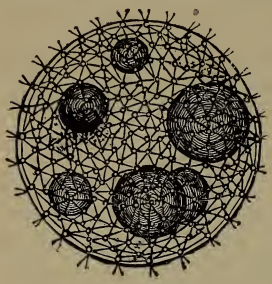


FIG. 68.—A Volvox colony, magnified about 45 times, showing young colonies within.

Practical Studies.—(*a*) In midsummer collect a few quarts of the surface water of weedy ponds, together with the pond-scums growing therein; put it into a shallow dish, and after an hour or so look carefully (with the naked eye) for Volvox. It will be seen as a minute green ball (from .5 to 1 millimetre in diameter) rolling slowly through the water. Now carefully transfer it to a slide along with enough pond scum to prevent crushing. Under a low power even many of the details of structure may be made out, and one or more young colonies in the interior may almost invariably be seen.

(*b*) In similar situations Pandorina may be obtained for study.

Systematic Literature.—Wolle, Fresh-water Algæ of the United States, 156–163.

ORDER 4. CONJUGATÆ. THE POND-SCUMS.

242. Here the sexual cells which unite are fixed; that is, they are not locomotive. The sexual act always takes place in the mature plant. No zoöspores are produced. This order includes many plants of great beauty and scientific interest. Of the five families here noticed the first three are composed of chlorophyll-bearing plants, while in the fourth and fifth they are destitute of chlorophyll.

243. The Desmids (*Desmidiaceæ*) are minute unicellular fresh-water plants. The cells are of very various forms, usually more or less constricted in the middle, and divided into two symmetrical half-cells. The cell-wall is more or less firm, but never siliceous.

244. The reproduction of desmids takes place by fission and by union; that is, asexually and sexually. In the first the neck uniting the two halves of the cell elongates and becomes divided by a transverse partition, so that instead of the original symmetrical cell there are now two exceedingly unsymmetrical ones (Fig. 69); these grow by the rapid enlargement of the new and small halves; eventually the two cells become symmetrical, by which time they have separated. This process may be repeated again and again.

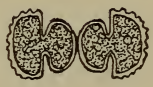


FIG. 69.—A desmid in process of fission. Highly magnified.

245. In the sexual process each of two cells which are

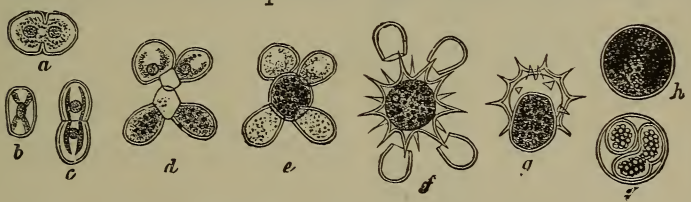


FIG. 70.—Sexual reproduction of a desmid (Cosmarium meneghinii). *a*, front; *b*, end; *c*, side view of the adult plants; *d*, two cells conjugating; *e*, young resting spore formed; *f*, ripe resting spore, with spiny wall—the four halves of the parent cells are empty; *g*, the resting spore germinating after a period of rest; *h*, the young cell escaped from resting spore; *i*, young cell dividing, showing two new plants, similar to *a*, placed crosswise in the interior of the cell. Magnified 475 times.

near one another sends out from its centre a tube, which meets the corresponding one from the other (*d*, Fig. 70). At the point of meeting the two tubes swell up hemispherically, and finally, by the disappearance of the separating wall, the contents unite and form a rounded

FIG. 71.—A common desmid, Closterium. Highly magnified.

resting spore (*e*), which soon becomes coated with a thick wall (*f*). After a longer or shorter time the resting spore may germinate, which it does by bursting its wall and dividing its contents into two parts, each of which finally becomes a new desmid (*g*, *h*, *i*).

246. The Diatoms (*Diatomaceæ*) are microscopic unicellular water-plants, resembling the desmids, but differing from them in having walls which are silicified, and in the chlorophyll being hidden by the presence of a yellow coloring matter (phycoxanthin). Each cell is usually composed of two similar portions, called the valves. Each valve may be described as a disk whose edge is turned down all around, so as to stand at right angles to the remainder of the surface, making the valve have the general plan of a pill-box cover. The two valves are generally slightly different in size, so that one slips within the other (*A*, Fig. 72), thus forming a box with double sides. In other cases the valves are simply opposed and do not overlap.

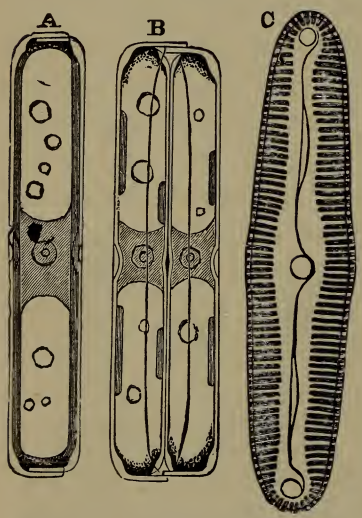


FIG. 72.—*A*, front view of a diatom, showing the overlapping walls; *B*, same view of a diatom undergoing fission; *C*, side or top view of a diatom (Navicula viridis), showing markings. Highly magnified.

247. The individuals may exist singly or in loose families; they are free, or attached to other objects by little stalks, and they are frequently imbedded in a mucous secretion. The free forms are locomotive, and may be seen in constant motion under the microscope: the mechanism of the motion is not certainly known.

248. In their reproduction diatoms resemble the desmids, the only differences being those made necessary by their rigid walls.

249. Diatoms are exceedingly abundant; they occur in both salt and fresh water, usually forming a yellowish layer at the bottom of the water, or they are attached to the submerged parts of other plants, and to sticks, stones, and other objects; they have been dredged from the ocean at great depths, and appear to exist there in enormous quantities. They are also found among mosses and other plants on moist ground. Great numbers occur as fossils, forming in many instances vast beds composed of their empty shells. The varied and frequently very beautiful markings of their valves have long made diatoms objects of much interest to the microscopist. The great regularity and the extreme fineness of the lines and points upon some have caused them to be used as microscopic tests.

250. The Pond-scums (*Zygnemaceæ*).—The plants of this family, which are all aquatic, are elongated unbranched filaments, composed of cylindrical cells arranged in single rows. The cells are all alike, and each one appears to be independent, or nearly so, of its associates. The filament is thus, in one sense, rather a composite body than an individual. The chlorophyll is generally arranged in bands or plates.

251. The vegetative increase of the number of cells takes place by the fission of the previously formed cells. The protoplasm in a cell divides, and a plate of cellulose forms in the plane of division. This is repeated again and again, and by it the filament becomes greatly elongated. It is interesting to note that this increase of cells, which here constitutes the growth of the plant-body, is that which in simpler plants is called the asexual mode of

reproduction. In the plants under consideration there is barely enough coherence of the cells to enable them to constitute a plant-body, and one can readily see that the same fission of the cells which here increases the *size* of the plant would, if the cells cohered less, simply increase the *number of individuals*.

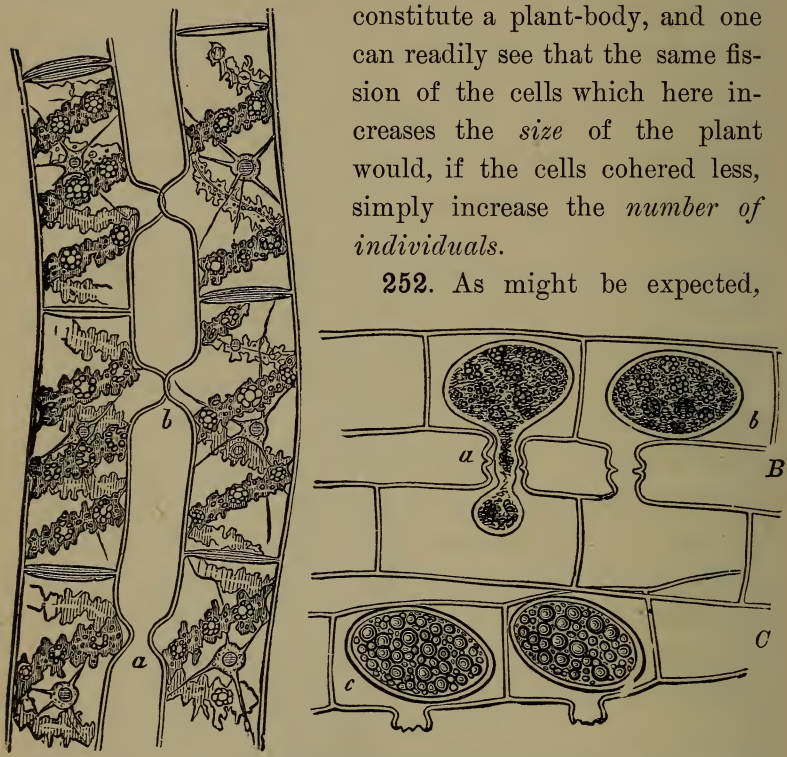


FIG. 73.—*A*, beginning of the sexual reproduction of a pond-scum (Spirogyra longata); *a*, beginning of the formation of lateral tubes; *b*, *c*, the tubes in contact. *B*, the protoplasm passing from one cell to the other at *a*; *b*, the mass of protoplasm formed by the union of the protoplasmic contents of the two cells. *C*, two young resting spores (*c*), each with a cell-wall. They contain numerous oil-drops, and are still enclosed by the walls of the parent cell. Magnified 550 times.

252. As might be expected, the filaments occasionally separate spontaneously into several parts of a considerable length, and the parts floating away give rise to new filaments. The separation takes place by the cells first rounding off slightly at the ends, so that their union is weakened at their corners; finally, only the centres of the rounded ends are left in slight contact, which soon breaks.

253. The sexual reproduction is well illustrated in Spirogyra, one of the principal genera. At the close of their growth in the spring the cells push out short tubes from their sides, which extend until they come in contact with similar tubes from parallel filaments (*A*, Fig. 73). Upon meeting, the ends of the tubes flatten upon each other, the walls fuse together, and soon afterward become absorbed, thus making a channel leading from one cell to the other (*B*, Fig. 73). Through this channel the protoplasm of one cell passes into the other, and the two unite into one mass, which becomes rounded and in a short time secretes a wall of cellulose around itself (Fig. 73, *B* and *C*). The resting spore thus formed is set free by the decay of the dead cell-walls of the old filament surrounding it; it then falls to the bottom of the water, and remains there until the proper conditions for its growth appear.

254. The germination of the resting spore is a simple process. The inner mass enlarges and bursts the outer hard coat; it then extends into a columnar or club-shaped mass, gradually enlarging upward from its point of beginning; after a while a transverse partition forms in it, and this is followed by another and another, until an extended filament is formed.

255. The Black Moulds (*Mucoraceæ*) are saprophytic and sometimes parasitic plants; they are composed of long branching filaments (*hyphæ*), which always form a more or less felted mass, the *mycelium;* when first formed, the hyphæ are continuous, but afterwards septa are formed in them at irregular intervals. The protoplasmic contents of the hyphæ are more or less granular, but they never develop chlorophyll. The cell-walls are colorless, except in the fruiting hyphæ, which are usually dark-colored or smoky (fuliginous); hence the name of Black Moulds.

256. The mycelium sometimes develops exclusively in the interior of the nutrient medium; in other cases it develops partly in the medium and partly in the air. In some species the mycelium may occasionally attach itself to the hyphæ of other plants of the same family, and even

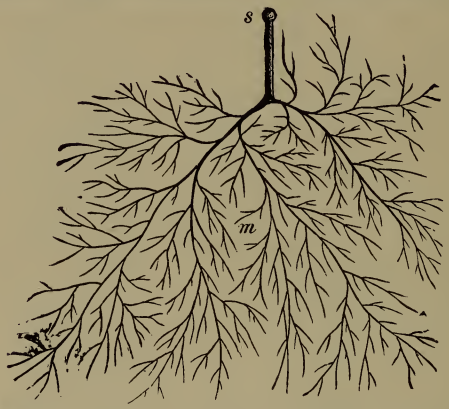


FIG. 74.—Diagram showing the mode of growth of Mucor mucedo. *m*, the mycelium; *s*, single spore-case, borne on an aerial erect hypha.

to nearly related species, and derive nourishment parasitically from them. It is doubtful, however, whether any species are entirely parasitic, and so far as parasitism occurs it appears to be confined to narrow limits; none, so far as known, are parasitic upon higher plants.

257. The reproduction of black moulds is asexual and sexual. In the asexual reproduction the mycelium sends up erect hyphæ (Fig. 74), which produce fewor many separable reproductive cells—the spores. The method of formation of the spores in a common black mould (Mucor mucedo) is as follows: The vertical hyphæ, which are filled with protoplasm, become enlarged at the top, and in each a transverse partition forms (*A*, *a*, Fig. 75), the portion above the partition (*b*) becomes larger, and, at the same time, the transverse partition arches up (*B*, *a*), finally ap-

pearing like an extension of the hypha, then called the *columella* (*C*, *a*). The protoplasm in the enlarged terminal cell (*b*) divides into a large number of minute masses, each of which surrounds itself with a cell-wall; these little

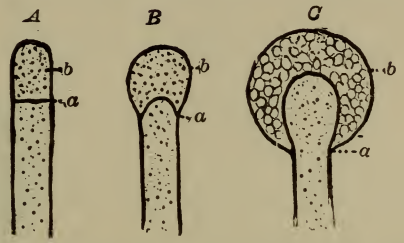


FIG. 75.—Diagrams showing mode of growth of the spore-case of Mucor mucedo. *A*, very young stage; *B*, somewhat later; *C*, spore-case with ripe spores. *a* in all the figures represents the partition-wall between the last cell of the filament and the spore-case, *b*.

cells are the spores, and the large mother-cell is now a spore-case, or sporangium.

258. The spores are set free in different ways: in some cases the wall of the spore-case is entirely absorbed by the time the spores are mature; in other cases only portions of the wall are absorbed, producing fissures of various kinds. The spores germinate readily when on or in a substance capable of nourishing them, by sending out one or two hyphæ, which soon branch and give rise to a mycelium. Spores may, if kept dry, retain their vitality for months.

259. Sexual reproduction takes place after the production of asexual spores. Two hyphæ, in the air or within the nutritive medium, come near each other, and send out small branches, which come in contact with each other (*a*, Fig. 76); these elongate and become club-shaped, and at the same time they become more closely united to each other at their larger extremities (*b*); a little later a transverse partition forms in each at a little distance from their place of union (*c*); the wall separating the new terminal

cells is now absorbed, and their protoplasmic contents unite into one common mass (*d*); the last stage of the process is

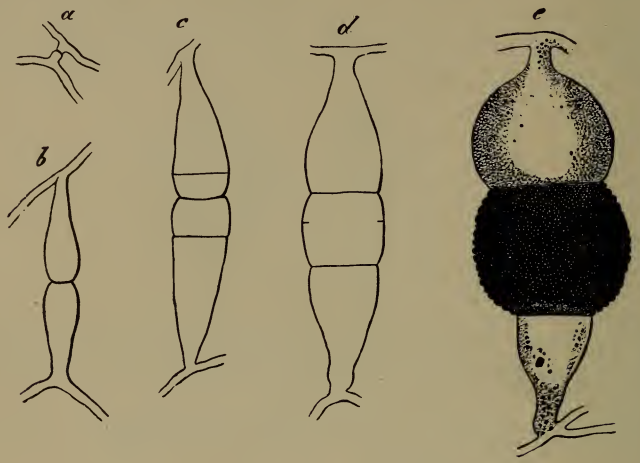


FIG. 76.—Conjugation of a Black Mould. *a*, two hyphæ near each other, and sending out short lateral tubes or branches, which come in contact; *b*, the branches grown larger; *c*, the formation of a partition near the end of each branch: *d*, absorption of the wall between the two branches, and the consequent union of the protoplasm of the end cells; *e*, resting spore fully formed. *e* magnified 90 times, the others nearly the same.

the secretion of a thick wall around the new mass, thus forming a zygospore (*e*).

260. The resting spore does not germinate until it has undergone desiccation, and has experienced a certain period of rest, when, if placed in a moist atmosphere, it sends out hyphæ which bear spore-cases. Resting spores appear never to form a mycelium: that is always the result of the growth of the spores from the spore-cases.

261. The Insect-fungi (*Entomophthoraceæ*) are well represented by the Fly-fungus (Entomophthora muscæ), which in the autumn is so destructive to house-flies. It consists of small tubular cells which grow in the moist tissues of the fly, and at last pierce the skin, producing minute terminal spores, which give the fly a powdery appearance.

These spores (called, also, conidia) may be seen as a whitish halo surrounding the spot to which the fly (now dead) has attached itself. Round and thick-walled resting spores have been observed in some species, and may be studied in the Grasshopper Fungus (Entomophthora grylli), which destroys great numbers of grasshoppers every autumn.

Practical Studies.—(*a*) Collect a quantity of pond-scum and other aquatic vegetation, and preserve in a dish of water. Mount portions of this material and search for desmids, using a ½-inch objective. Two-lobed or star-shaped desmids of a bright-green color may frequently be found. A large lunate desmid (Closterium, Fig. 71) is often still more common. In the latter the clear protoplasm at each end is always streaming rapidly.

(*b*) Collect a little of the brownish-yellow scum which in early spring gathers on the top of the water of brooks, ditches, and pools. Mount in water and examine with a high power. Hundreds of diatoms may be seen moving rapidly across the field in every direction. In any such preparation many species of various shapes will be found. The prevailing form, however. is generally elongated and somewhat diamond-shaped.

(*c*) Study in like manner the slimy coating upon dead leaves and twigs in water in the summer for diatoms. On some of these very fine markings may be found.

(*d*) Collect a quantity of bright-green pond-scum, which always abounds in shallow ponds and pools, and preserve in a dish of water. Collect, also, some of the same which has begun to turn yellow and brown. Upon mounting a bit of the first in water and examining with a high power it will be found to consist of threads of cylindrical cells, each containing one or more spiral chlorophyll-bands (Spirogyra, Fig. 73) or star-shaped chlorophyll-bodies (Zygnema). Upon mounting some of the second collecting here and there the formation of resting spores may be observed. In all cases care must be taken not to mount *too great a quantity* of the material, nor to injure the plants by rough handling.

(*e*) In the study of black moulds it is mostly necessary to make use of alcohol for freeing the specimens of air; afterwards they usually require to be treated with a dilute alkali, (as a weak solution of ammonia or potassic hydrate), which causes the hyphæ to swell up to their original proportions.

(*f*) Cut a lemon in two, and, squeezing out most of the juice, expose the two halves to the air of an ordinary living-room or school-

room for a few days, when various moulds will begin to develop. Under favorable circumstances black mould will predominate. It can be told by its dark color and the minute round black spore-cases on the ends of the erect hyphæ. Mount a few hyphæ (as directed in *e* above) and examine hyphæ, spore-cases, and spores.

(*g*) Moisten a piece of perfectly fresh bread, and then sow here and there on its surface a few spores of black mould; cover with a tumbler or bell-glass. In a few hours a new crop of Black Mould will begin developing.

(*h*) The more common black moulds, Mucor mucedo, M. racemosus, and Ascophora mucedo, are common on many decaying substances. Syzygites aspergillus occurs on decaying toadstools and other large fungi. Hydrogera obliqua and Chætocladium jonesii occur on animal excrement. Phycomyces nitens grows on oily or greasy substances, as old bones, oil-casks, etc.

(*i*) Place several clean glass slides in contact with a culture of black mould, as described in (*g*). By removing these at different times the various stages of growth of the mould may be easily studied.

(*j*) In the latter part of summer and in the autumn examine the dead flies which adhere to window-panes, door-casings, and especially to wires and strings hanging from the ceiling. The whitish powder around the fly will indicate the presence of the fly-fungus. Mount some of this white powder in water and examine under a high power. Tear out small bits of the distended abdomen of the fly, and examine for internal portions of the parasite.

(*k*) In the autumn look for dead grasshoppers attached to the tops of weeds and grasses. Examine their interior tissues for thick-walled resting spores of Entomophthora grylli.

(*l*) For future study in the laboratory the aquatic Conjugatæ should be preserved in bottles of water containing just enough alcohol, glycerine, or carbolic acid to prevent their decay. One fourth or fifth of the first and second, and enough of the last to give a decided odor, will usually do well enough.

Systematic Literature.—Wolle, Desmids of the United States. Wolle, Diatomaceæ of North America. Wolle, Freshwater Algæ of the United States. Saccardo, Sylloge Fungorum, **7**[1], Flora of Nebraska, **1**. 35–53. *pl. 5–11, 14, 15.*

Order 5. SIPHONEÆ. The Green Felts.

262. The plant-body in this important and interesting order is a branched filament, in which the protoplasm is continuous. These plants are, however, not to be consid-

ered single-celled, but rather rows or aggregations of cells which have not become separated from one another by partitions. Such a plant-body is a *cœnocyte*.

263. Botrydium (*Hydrogastraceæ*).—One of the simplest of the Green Felts is the little Botrydium (Fig. 77), which occurs on the surface of damp ground. It consists of a nearly globular, green body above the ground, with tapering, colorless branches below, penetrating the soil. It is not, as one might suppose, a single cell, but an aggregation of cells, the plant being non-septate. It reproduces by forming zoöspores, some of which develop directly into new plants, while others unite and form resting spores.

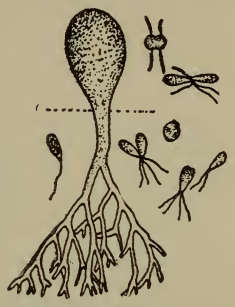


FIG. 77.—A plant of Botrydium, highly magnified, with conjugating zoöspores.

264. The Green Felts (*Vaucheriaceæ*) are good representatives of one of the highest families in this order. They are coarse, green, tubular plants which grow in abundance on the moist earth in the vicinity of springs, and in shallow running water, forming dense felted masses.

265. The asexual reproduction consists of a separation of a part of the plant-body, sometimes a swollen lateral branch, sometimes only the protoplasm of such a branch. In the latter case the protoplasm may escape as a zoöspore (*A*, Fig. 78) which eventually forms a wall around itself, and then proceeds to elongate into a new plant-body.

266. Sexual reproduction takes place in lateral branches also. Both antherids and oögones develop as lateral protuberances upon the main stem (*og*, *og*, *h*, Fig. 78). The male organ (antherid) is long and rather narrow, and soon much curved; its upper portion becomes cut off by a par-

tition, and in it very small biciliate antherozoids are developed in great numbers. The female organ (oögone) is short and ovoid in outline, and usually stands near the male organs. In it a partition forms near its point of union with the main tube; the upper portion becomes an oögone, and its protoplasm condenses into a rounded body, the germ-cell: at this time the wall of the oögone opens,

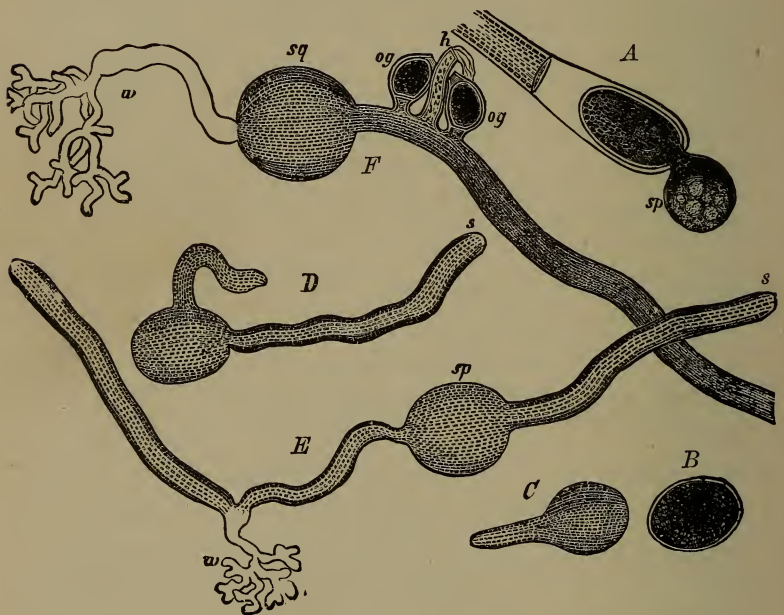


FIG. 78.—Reproduction of green felt (Vaucheria sessilis). *A*, formation of a zoöspore; *B*, zoöspore come to rest; *C*, zoöspore germinating; *D*, *E*, young plants; *w*, root-like holdfasts; *F*, plant with sexual organs. Magnified about 30 times.

and permits the entrance of the antherozoids which were set free by the rupture of the antherid-wall.

267. Upon coming into contact with the germ-cell the antherozoids mingle with it and disappear; the germ-cell immediately begins to secrete a wall of cellulose about itself, and it thus becomes a resting spore. After a period

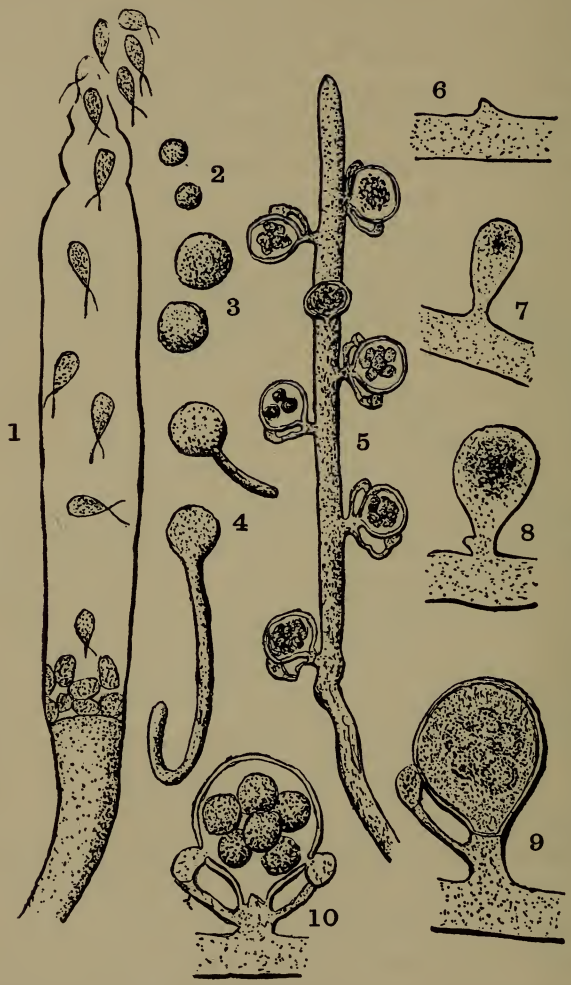
of rest the thick wall of the resting spore splits, and through the opening a tube grows out which eventually assumes the form and dimensions of the full-grown plant.

268. The Water-moulds (*Saprolegniaceæ*) are colorless saprophytes or parasites, more frequently the latter; they are generally to be found in the water, attached to the bodies of living or dead fishes, crayfishes, etc., or occasionally in the moist tissues of animals out of the water. The plant-body is greatly elongated and branched, and all its vegetative portion is continuous; the reproductive portions only are separated from the rest of the plant-body by partitions.

269. The asexual reproduction is very much the same as in green felt. It may be briefly described as follows: The protoplasm in the end of a branch becomes somewhat condensed, a partition forms, cutting off this portion from the remainder of the filament, and the whole of its contents becomes converted by internal cell-division into zoöspores provided with one or two cilia (Fig. 79, 1). These soon escape from a fissure in the wall and are active for a few minutes, after which they come to rest and their cilia disappear (2 and 3). In one or two hours they germinate by sending out a filament (4), from which a new plant is quickly produced.

270. The sexual organs also bear a close resemblance to those of green felt. The oögones are spherical, or nearly so (in most of the species), and contain from two to many germ-cells, which are fertilized by means of antherids, which usually develop as lateral branches just below the oögones. In some species the antherids and oögones are upon the same plants, and in such cases the fertilization takes place by the direct contact of the antherid and the

passage of its contents into the oögone by means of a tubular process from the former; in other species the plants



79.—Showing reproduction in Water-moulds. 1, 2, 3, 4, asexual reproduction; 5 to 10, sexual reproduction; 6 to 9 show development of oögones and antherids. Highly magnified.

are dicœcious, and in them the antherids produce motile antherozoids, by means of which the fertilization is ef-

fected. After fertilization each germ-cell becomes covered with a wall of cellulose and is thus transformed into a resting spore.

271. What is given above may be taken to illustrate the general mode of reproduction in the family. It presents much variation in the different genera and species, and in some cases the sexual organs are functionless, the resting-spores forming without an actual fertilization. The mature resting-spores are double-walled, the outer (exospore) being thick, and the inner (endospore) thin. After a considerable period of repose the resting-spores germinate by sending out a tube, as in Green Felt.

272. The Downy Mildews and White Rusts (*Peronosporaceæ*) live parasitically in the interior of higher plants. They are composed of long branching tubes, whose cavities are continuous throughout. They grow between the cells of their hosts, and draw nourishment from them by means of little branches (*haustoria*), which thrust themselves through the walls (Fig. 80).

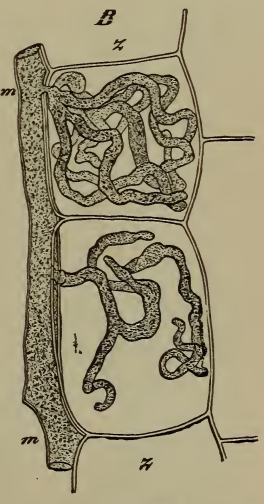


FIG. 80.—Showing one of the hyphæ (*m*, *m*) of a Mildew, sending suckers (haustoria) into the cells (*z*, *z*) of its host. Magnified 300 times.

273. The asexual spores (conidia) are produced upon branches (conidiophores) which protrude through the epidermis of the host. In the Downy Mildews (species of Peronospora, Phytophthora, Plasmopara, etc.) these branches find their way through the breathing-pores, and bear their spores singly upon lateral branchlets (Fig. 81); in the White Rusts

(species of Albugo) the conidia-bearing branches collect

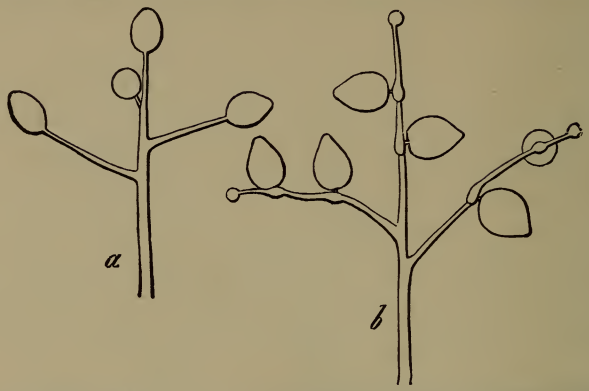


FIG. 81.—Showing tips of two conidiophores of Potato-mildew (Phytophthora infestans). Highly magnified.

under the epidermis and rupture it. Here the conidia are borne in chains or bead-like rows (Fig. 82).

FIG. 82.—Showing conidiophores and conidia of the White Rust of Peppergrass. Magnified 400 times.

274. In some species the conidia germinate by forming a tube; in others they divide internally and finally emit many zoöspores. The latter eventually protrude a tube and bore their way into the cells of the host (Fig. 83, *a* to *i*).

275. The sexual reproduction always takes place in the intercellular spaces of the host. Lateral branches of two kinds appear upon the hyphæ; those of one kind (the young oögones) become greatly thickened and finally assume a globular shape (Fig. 84, *o*); the other branches (the young antherids) become elongated and club-shaped (Fig. 84, *n*). The antherids bend and come in contact with the oögones, and soon each thrusts out a small tube which penetrates the oögone, reaching the

germ-cell. The protoplasm of the antherid is thus transferred directly to the germ-cell (Fig. 84, *A*, *B*, *C*). After

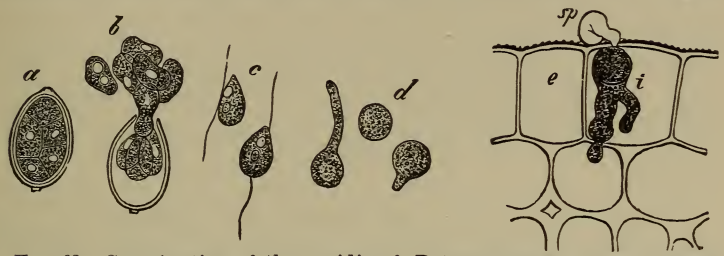


FIG. 83.—Germination of the conidia of Potato-mildew. *a*, *b*, *c*, formation of zoöspores; *d*, growth of zoöspores; *sp*, a zoöspore growing into the cells of the plant, *e*, *i*.: Magnified about 400 times.

FIG. 84.—Sexual organs of a Mildew. *o*, öogones; *n*, antherids. *A*, youngest stage; *B* and *C*, older stages. Magnified 350 times.

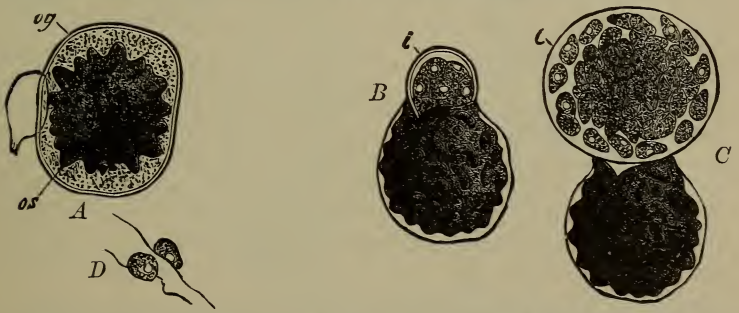


FIG. 85.—Resting spores of White Rust of Peppergrass; at *A* still surrounded by oögone. *B*, *C*, formation of zoöspores: *D*, free zoöspores. Magnified 400 times.

fertilization the germ-cell secretes a thick double wall, and so becomes a resting spore.

276. The resting-spores remain in the tissues of the host until the latter decay, which is generally in the spring. Germination then takes place, in some species by the production of a tube, in others by the division of the protoplasm into zoöspores (Fig. 85, *B, C, D*), whose subsequent development is like that described above in case of the conidia.

Practical Studies.—(*a*) Look for Botrydium in damp weather in the summer on the hard, smooth ground of unused paths. It often appears on compact soil in greenhouses in the winter.

(*b*) Collect a quantity of Green Felt and preserve it in a dish of water. After a few hours a large number of zoöspores may be observed collected at the edge of the water nearest to the light.

(*c*) Examine carefully mounted specimens of the bright green filaments, and look for the thickened lateral branches which produce the zoöspores.

(*d*) Select some of the oldest, yellowish filaments. Mount and examine with a low power for the sexual organs. In collecting specimens for the study of the sexual organs it is necessary always to take those masses which are yellowish and appear to be dying or dead.

(*e*) Throw a dead fish into a pool of water in the summer, and examine it after a few days, when it will probably be found covered with a mould-like growth. Remove a few filaments and look for the formation of zoöspores. The same Water-mould (Saprolegnia ferax) may often be found upon the bodies of young fishes, especially in fish-hatching houses.

(*f*) In the spring the leaves of shepherd's-purse and peppergrass may often be found covered underneath with a white mould-like growth (Peronospora parasitica). Carefully scrape off a little of this growth and mount first in alcohol, afterwards adding a little potassic hydrate. The irregularly branching hyphæ will be seen to bear here and there their white, broadly ellipsoidal conidia. Similar studies may be made of the Grape-mildew (Plasmopara viticola) on grape-leaves in autumn, and the Lettuce-mildew (Bremia lactucæ) on cultivated and wild lettuce from spring to autumn.

(*g*) Make very thin cross-sections of a leaf affected with a Downy Mildew, when the latter has passed the period of its greatest vegetative activity. Mount in alcohol (to drive out air-bubbles), then add potassic hydrate, and look for the resting-spores, which in some species are of a dark brown color.

(*h*) White Rusts occur on many plants: one (Albugo candida) on shepherd's-purse, peppergrass, radish, etc.; another (A. bliti) on Amaranthus; and another (A. portulacæ) on purslane. For conidia make very thin cross-sections of leaves, through a white-rust spot, and mount as above. The resting-spores (which are dark brown) are easily obtained in the leaves of Amaranthus and purslane.

Systematic Literature.—Wolle, Freshwater Algæ of the United States, 146–154. Saccardo, Sylloge Fungorum, **7**[1]. Flora of Nebraska, **1** : 53–60, *pl. 12, 13, 15, 16*.

Order 6. **Confervoideæ.** The Confervas.

277. These are always multicellular, green plants, with the cells mostly arranged in simple or branched filaments, rarely arranged in a plate or membrane. No species are hysterophytic. The gametes are equal and motile in the lower families, but in the higher ones they consist of antherozoids and fixed oöspheres.

278. The Sea-lettuce (*Ulva*, Fig. 86, *A*), which is com-

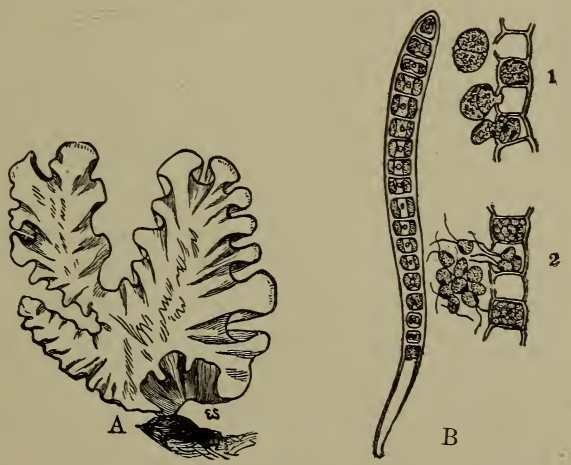


Fig. 86.—*A*, a plant of Sea-lettuce (Ulva lactuca). Natural size. *B*, a young plant of Ulothrix zonata. 1, escape of asexual zoöspores; 2, sexual zoöspores. × 200. (From Strasburger.)

mon along the coast and in brackish waters, growing upon stones, wharf-timbers, etc., and resembling small lettuce-

leaves, is the type of the family *Ulvaceæ*. It reproduces by zoöspores. The plant is composed of two layers of cells, and in any of these, by internal cell-formation, zoöspores may be produced; these escape into the water, where they swim about by means of their cilia, after a time coming to rest and developing directly into new plants, or conjugating and forming resting-spores.

279. The common **Conferva** (*Ulotrichiaceæ*) of our watering-troughs and fountains, consists of slender unbranched threads which are attached at one extremity by a colorless "root-cell." Their reproduction is very much like that of the Sea-lettuce, any cell being capable of forming zoöspores (Fig. 86, *B*).

280. In the common **Water-flannel** (*Cladophora*) of our creeks and rivers we have a good example of the family *Cladophoraceæ*. It is a large, dark green, much-branched plant, which attaches itself to stones and timbers in the water. It grows so vigorously that it soon forms long matted masses, often several metres in length, which float and wave back and forth in the currents of water. It produces myriads of zoöspores.

281. Family Oedogoniaceæ.—The plants constituting this family are composed of articulated, simple, or branched filaments, which are attached to sticks, stones, earth, or other objects by root-like projections of the basal cells. The cells are densely green throughout. They inhabit ponds and slow streams, and form green or brownish masses which fringe the sticks and other objects in the water.

282. The asexual reproduction of Oedogoniaceæ is very curious. During the early and active growth of the plants the protoplasm of certain cells escapes as a large zoöspore (Fig. 87, *A* and *B*); it is provided with a crown of cilia

about its smaller hyaline end, by means of which it swims rapidly hither and thither in the water (*C*). After a time it comes to rest, clothes itself with a cell-wall, and sends out from its smaller end root-like prolongations (*D*), which attach it to some object; it now elongates, and at length forms partitions, taking on eventually the form of the adult filament. It sometimes happens that before the new plant resulting from the growth of a zoöspore has formed its first partition the protoplasm again abandons its cell, to be for a second time a zoöspore (*E*).

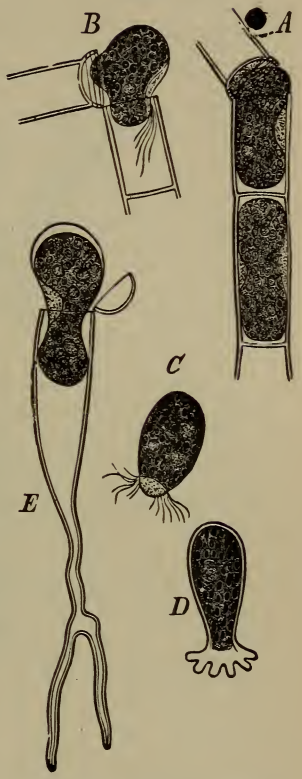


FIG. 87.—Asexual reproduction of Oedogonium. *A*, fracture of a filament; *B*, escape of protoplasm and formation of a zoöspore; *C*, swimming zoöspore; *D*, zoöspore at rest, and sending out root-like prolongations from the hyaline end; *E*, a young plant composed of only one cell, with its protoplasm escaping. Magnified 350 times.

283. In the sexual reproduction of the plants of this class the female organ consists of a rounded germ-cell situated within a cavity —the oögone; it is developed from one of the cells (sometimes two) of the filament by a condensing and rounding off of the protoplasmic contents; when the germ-cell is fully mature, an opening is formed in the oögone wall for the ingress of the antherozoids (*A* and *B*, Fig. 88). One or more antherozoids are produced in certain small cells of the same or another filament; in shape they resemble the zoöspores mentioned above.

Upon escaping into the water they swim about vigorously, eventually making their way through the opening in the oögone, and then burying themselves in the substance of the germ-cell (*B*, *z*, Fig. 88). After fertilization the

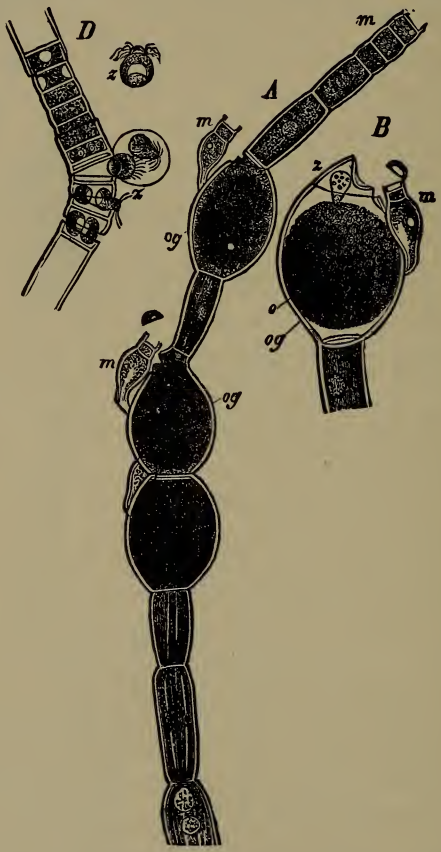


FIG. 88.—Showing the sexual state of an Oedogonium. *A*, part of a filament with three oögones, *og*; *m*, *m*, small filaments (dwarf males) which in this species produce antherozoids; *B*, an oögone at time of fertilization; *D*, part of filament of another species, showing escape of antherozoids. Highly magnified.

germ-cell becomes covered with a thick and colored (brown or red) coat, and it then becomes a resting spore.

284. After a period of rest the resting spore germinates by rupturing its thick coat and permitting the escape of

the contents, enclosed in a thin envelope; by this time the protoplasm has divided into four portions, which take on an oval form and develop a crown of cilia. They soon escape from the investing membrane, and after a brief period of activity grow into an ordinary filament in exactly the same manner as the zoöspores.

Practical Studies.—(*a*) Collect fresh specimens of Sea-lettuce, put into a jar of water, and watch the production of zoöspores. Enteromorpha, which is common in brackish waters in the interior, may be substituted for Ulva.

(*b*) Study Conferva in like manner. It may be grown in an aquarium very easily, so as to be obtainable at any time, even in the winter.

(*c*) Collect a quantity of Water-flannel, and put it in a large dish of water, leaving it overnight. Next morning the side of the dish which is nearest to the light will show a green band at the water's edge, due to the myriads of zoöspores which escaped during the night. Mount a drop of water and search for zoöspores. Occasionally the escape of zoöspores may be seen by mounting a number of filaments and searching carefully.

(*d*) Specimens of Oedogonium may be obtained by examining the small sticks and stems of aquatic plants from quiet waters. They may be recognized by the enlarged cells (oögones).

Systematic Literature.—Wolle, Freshwater Algæ of the United States, 65–146. De Toni, Sylloge Algarum, **1** : 1–390. Flora of Nebraska, **1** : 60–68, *pl. 17–22.*

Class 3. **Phæophyceæ.** The Brown Algæ.

285. The plants of this class are commonly known as the Brown Algæ, and Brown Seaweeds on account of their dark color. While they contain chlorophyll, it is more or less hidden by an additional coloring matter, phycophæin. Some of the simpler plants are minute few-celled filaments or masses, but in the higher families the plant-body is large and massive, and many metres in extent. They are almost entirely confined to the waters of the ocean. No members of this class are hysterophytic. They number all told about 1100 species.

There are three orders of Brown Algæ, as follows :

Gametes alike and motile (ciliated zoöspores),
Order 7, PHÆOSPOREÆ
Gametes unlike and non-motile (antherozoids and oöspheres),
Order 8, DICTYOTEÆ
Antherozoids motile, the oöspheres non-motile....Order 9, FUCOIDEÆ

ORDER 7. PHÆOSPOREÆ. THE KELPS.

286. Kelp.—The large, flat, leaf-like kelps (Laminaria, "Devil's Apron," Costaria, etc.) may be taken to illustrate the larger forms (family *Laminariacæ*). The "leaf" portion is sometimes from one to six metres long and nearly a metre in breadth, while its stalk sometimes attains a length of two to four metres. It is held to rocks and stones at or below low-water mark by means of root-like processes.

FIG. 89. — Plant of Costaria reticulata, showing zoösporangial areas (one-sixth natural size), with section showing zoösporangia below, × 330.

287. The zoöspores, which have two cilia, are produced in specialized cells (zoösporangia) on the surface of the plant (Fig. 89). These occupy definite areas on the plant-body, and compose the "fruit," so called. In Laminaria the zoösporangia form bands or spots on the central part of the leaf. The zoöspores after escaping from the zoösporangia swim about for a time and then develop directly into new plants. The union of zo spores to form a resting-spore (zygospore) has been observed in but few cases, and not at all in the larger and more common species.

Practical Studies.—(*a*) Study the tissues of Laminaria and other kelps in cross and longitudinal sections.

(*b*) Make sections through the patches of zoösporangia ("fruits") and examine the zoösporangia and paraphyses.

(*c*) Where fresh material cannot be secured, the kelps may be studied very well from alcoholic specimens, which can be obtained from dealers in botanical supplies.

Systematic Literature.—Farlow, Marine Algæ of New England, 61–98.

The study of the Dictyoteæ may well be omitted by the beginner.

Order 9. **FUCOIDEÆ.** The Rockweeds.

288. The plants of this order are entirely marine. In some cases the development of the plant-body is unusually perfect, showing a differentiation into parts which have a close resemblance to roots, stems, and leaves. In size they approach the flowering plants. Their tissues, too, show a high degree of differentiation; the cells are arranged in cell-masses, and these are differentiated into several varieties of parenchyma, approaching, in some instances, to the condition which prevails in the Mosses and their allies.

289. With the foregoing there is found a marked differentiation of portions of the plant-body into general reproductive organs, analogous to the floral branches of higher plants. The sexual organs are developed upon modified branches, which differ more or less in shape and appearance from the ordinary ones.

290. In common Rockweeds (Fucus) of the seashore the sexual organs are found in the thickened ends of the lateral branches (*A*, Fig. 90). They occur on the walls of cavities termed *conceptacles*, which are spherical, with a small opening at the top (*B*, Fig. 90). The conceptacles are at first portions of the general surface, and afterward become

depressed and walled in by the overgrowth of the surrounding tissues; they are thus in reality portions of the general surface.

291. The walls of the conceptacles are clothed with pointed hairs, which in some species project through the

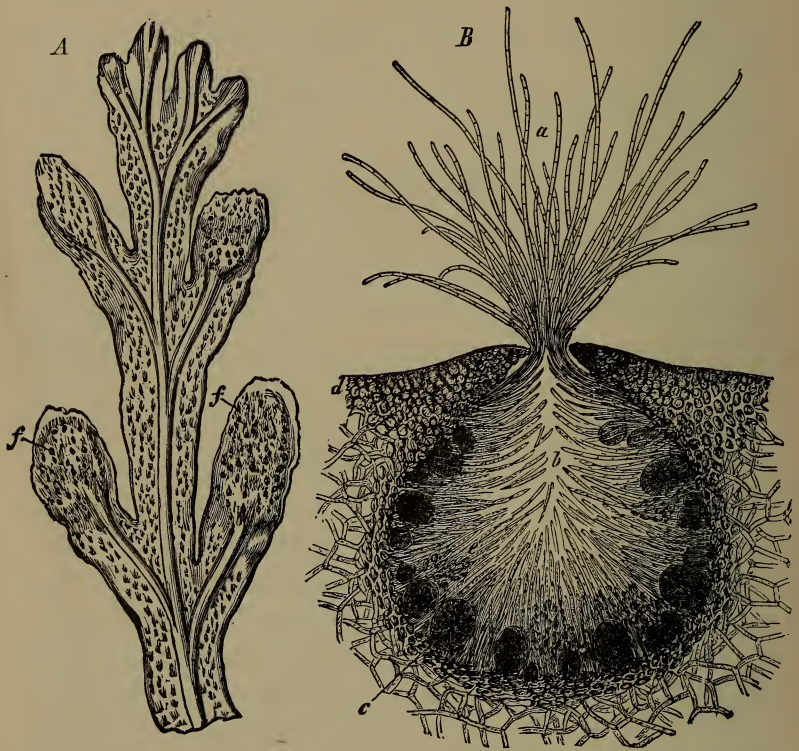


FIG. 90.—*A*, end of branch of a Rockweed (Fucus evanescens), natural size; *f*, *f*, conceptacles. *B*, magnified section through a conceptacle, showing hairs *a*, *b*; oögones, *c*; antherids, *e*.

opening, and among these are found the sexual organs, which are themselves, as Sachs has pointed out, modified hairs. The antherids are produced as lateral branches of hairs (*A*, Fig. 91); each antherid is a thin-walled cell, whose protoplasm breaks up into a large number of biciliate antherozoids, which escape by the rupture of the sur-

rounding wall (*B*). Before rupturing, however, the antherids detach themselves and float in the water with their contained antherozoids.

292. The oögone is a globular or ovoid short-stalked body containing eight germ-cells. The oospheres escape from the oögone surrounded by an investing membrane, which floats out through the opening of the conceptacle, where it finally ruptures and sets the germ-cells free (*II*, Fig. 91). The antherozoids, which are liberated at about the same time,

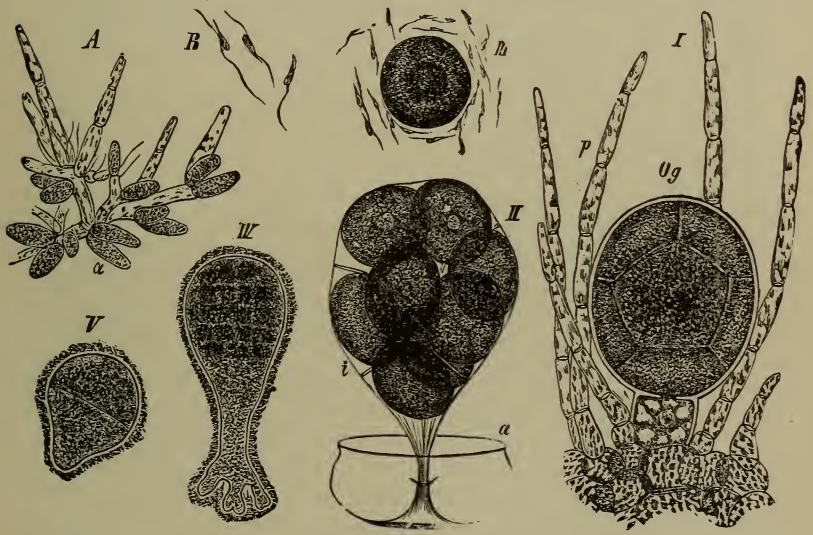


FIG. 91.—Sexual organs of Rockweed (F. vesiculosus). *A*, antherids; *B*, antherozoids; *I*, oögone and hairs; *II*, escape of oöspheres; *III*, oösphere surrounded by antherozoids; *IV*, *V*, germination of oöspore. (Magnified 160 times; *B*, 360).

gather around the inactive oöspheres in great numbers, and by the vigor of their movements sometimes actually give them a rotary motion (*III*). The result of their coming together is the fertilization of the oöspheres, and their transformation into oöspores by the secretion of a wall of cellulose on each one.

293. In germination the oöspore lengthens and undergoes division into numerous cells; at the same time it

elongates below into root-like processes, which serve to hold fast the new plant (*V*, *IV*).

Practical Studies.—(*a*) Secure specimens of Rockweeds, fresh, alcoholic, or dry. Fresh ones may easily be found along the beach of the ocean after a storm. Alcoholic and dry specimens can easily be procured by purchase or exchange. Make thin cross-sections through the conceptacles in the thickened ends of the branchlets. When mounted in water, even the sections from the dry specimens will frequently show the sexual organs quite well. It must be remembered that some species are diœcious, i.e., have the antherids on one plant and the oögones on another.

(*b*) Make very thin cross and longitudinal sections of different portions of the plant-body, and study the tissues. Note particularly the boundary tissue (epidermis), and the cells constituting the midribs and harder portions of the stems and leaves.

(*c*) The following key to the genera of American Fucaceæ will be helpful in their study.

I. Plant branched:

1. Leafy; air-bladders stalked, separate.....Sargassum.
   In addition to half a dozen species of both coasts, the Gulfweed (Sargassum bacciferum) may be mentioned, which floats in great quantity in mid-Atlantic, constituting the so-called Sargasso Sea. Its proper home is in the West Indian region, where it grows attached to rocks.
2. Leaves spirally inserted, bearing air-bladders on their blades (southern).....Turbinaria.
3. Leaves 2-ranked, bearing air-bladders on their petioles (Western).....Phyllospora.
4. Plant pinnatifid; air-bladders several-celled, terminal on the branchlets (western).....Halidrys.
5. Plant dichotomous, the parts flat and provided with a midrib (both coasts).....Fucus.
   This contains the proper Rockweeds of the seaside. Eight species occur in the United States.
6. Plant irregularly dichotomous, the linear parts destitute of a midrib (eastern).....Ascophyllum.
7. Plant much branched, bushy, the branches filiform (Western).....Cystoseira.

II. Plant reduced to a top-shaped or cup-shaped vesicle (doubtfully American).....Himanthalia.

Systematic Literature.—Farlow, Marine Algæ of New England, 99–104.

CHAPTER IX.

BRANCH III. CARPOPHYTA.

THE FRUIT-TANGLES.

294. The distinguishing characteristic of the plants which constitute this vast division is the formation of a spore-fruit (sporocarp) as a result of fertilization. The spore-fruit consists essentially of two different parts, viz., (1) a fertile part, which either directly or indirectly produces spores, sometimes a few, or even one, or a very great number ; (2) a sterile part, consisting of cells or tissues developed from the cells adjacent to the fertile part, and so formed as to envelop it.

295. This immense group consists typically of plants with chlorophyll, to which are added large numbers of hysterophytic, chlorophyll-less species. In the former the spore-fruit is small in proportion to the size of the vegetative parts of the plant ; but in the latter, where the vegetative parts are greatly reduced, the spore-fruit is proportionately large. In this the hysterophytes of the Carpophyta are like those of the flowering plants, in which the vegetative or assimilative organs are smaller than in those which contain chlorophyll ; thus the very large spore-fruits of many of the larger fungi, and their relatively small mycelium, may be compared to the large reproductive organs and the reduced stems and leaves of the Vine-rape (Rafflesia) of Sumatra.

296. The female organ in this division is called a carpogone, and consists of a single enlarged cell, or of several cells of a special form. In some cases a projection, called the trichogyne, is attached to the carpogone; its function appears to be the conveyance to the carpogone of the fertilizing matter received from the antherid.

297. The antherid is much more variable in structure than the female organ. In some cases it is applied directly to the carpogone in fertilization, while in others it produces antherozoids. The antheroids and carpogones are often sterile in the hysterophytic species.

298. The plant-body shows in general a more perfect development in the Carpophyta than in the preceding branches. While it is but little developed in the hysterophytic species, it is well developed in many of the Red Seaweeds and the Stoneworts, in which there is often a considerable amount of differentiation of the plant-body into caulome and phyllome.

Five classes may be distinguished, as follows:

Minute green fresh-water plants; fruit-spores few,
Class 4, COLEOCHÆTEÆ

Red or purple mostly marine plants; fruit-spores many,
Class 5, RHODOPHYCEÆ

Mostly parasites; fruit-spores many, enclosed in sacs,
Class 6, ASCOMYCETEÆ

Mostly saprophytes; fruit-spores many, on stalks,
Class 7, BASIDIOMYCETEÆ

Large green fresh-water plants; fruit-spore one,
Class 8, CHAROPHYCEÆ

CLASS 4. **COLEOCHÆTEÆ.** THE SIMPLE FRUIT-TANGLES.

299. The genus **Coleochæte,** representing the single order COLEOCHÆTACEÆ, shows us the simplest form of sexual reproduction among the Carpophytes. The species are all minute green fresh-water plants, composed of branching

filaments, which are arranged radially; the diameter of each cushion-like mass is from 1 to 2 mm. (.04 to .08 in.) or less.

300. Asexual reproduction is by means of ciliated zoöspores, one of which may form in each cell and escape through a round hole in the cell-wall (*D*, Fig. 92).

301. In the sexual process the female organ, the carpogone, is a single cell, wide below and tapering above into a long slender canal, the trichogyne, which is open at its apex (*A*, *og*, Fig. 92). In the swollen basal portion there

FIG. 92.—Coleochæte. *an*, antherids; *og*, carpogones, each with a trichogyne; *z*, *z*, antherozoids; *B*, fertilized carpogone, surrounded by the covering, *r* ("pericarp"), the whole forming the spore-fruit; *C*, spore-fruits burst open, showing interior tissues; *D*, zoöspores from *C*. Magnified 350 times.

is a considerable mass of protoplasm, which is the essential part to be fertilized. The male organs, the antherids, are formed as flask-shaped protuberances which grow out of adjoining cells. In each antherid a single oval biciliate antherozoid is formed (*A*, *z*, *z*, Fig. 92).

302. Fertilization is doubtless effected by these antherozoids coming in contact with the protoplasm of the carpogone, but the actual entrance of the former has not yet been seen. After fertilization the protoplasm in the carpogone increases considerably in size, and forms a cellulose coat of its own. The cells which support the carpogone send out lateral branches, which grow up and closely surround it, finally covering it entirely (excepting the trichogyne) with a cellular thick-walled "pericarp" (*B, r*). The whole mass, including the fertilized carpogone and its investing pericarp, constitutes the simplest form of spore-fruit (the *sporocarp*).

303. The further growth of the spore-fruit takes place the next spring by the swelling of the protoplasmic contents, and the consequent rupture of the pericarp; the inner portion divides into several cells, *C* (the proper fruit-spores), which give rise to zoöspores closely resembling those developed from the vegetative cells. From each zoöspore a new plant eventually arises.

This class contains but twelve or thirteen species, falling within the single order (10) Coleochætaceæ.

Practical Studies.—(*a*) These little plants occur in fresh-water pools as little green masses adhering to leaves, sticks, the stems of living plants, etc. According to Wolle, we have five species.

(*b*) The sexual process and the development of the sexual organs occur in May, June, and July.

Systematic Literature.—Wolle, Fresh-water Algæ of the United States, 63–65. De Toni, Sylloge Algarum, **1** : 6–12. Flora of Nebraska, **2** : 119, 120. *pl. 23.*

Class 5. **Rhodophyceæ.** The Red Seaweeds.

304. The plants of this class, which are almost without an exception marine, are among the most beautiful and interesting members of the vegetable kingdom. All have

some shade of red or purple which sometimes becomes exceedingly rich ; while for beauty of outline and delicacy of branching they stand unrivalled among plants.

305. To a great extent they grow in the deep water below low-water mark, far beyond the reach of the ordinary collector. There is therefore a good deal of difficulty involved in their study. The greater part of the material which the student secures for study is that which the storms have washed ashore from the deeper waters.

306. The plant-body varies from small branching filaments, on the one hand, to expanded leaf-like growths showing a considerable degree of complexity, with the beginning of a differentiation of the cells into several kinds of tissues. All contain chlorophyll, which, however, is

FIG. 93.

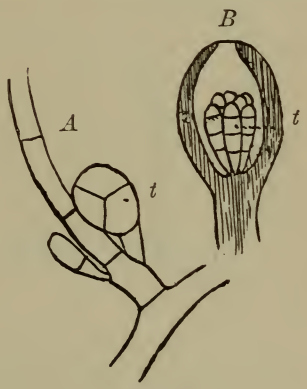


FIG. 94.

FIG. 93.—A Red Seaweed (Plocamium coccineum). About natural size.
FIG. 94.—Tetraspores of Red Seaweeds. *A*, of Lejolisia mediterranea; *t*, tetraspores. *B*, of Corallina officinalis; *t*, tetraspores in a cup-shaped extremity of a branch.

generally hidden by the presence of a red or purple coloring-matter (phycoerythrin).

307. The asexual reproduction takes place by means of spores, which, from almost always forming in fours, are

known as tetraspores (*A* and *B*, *t*, *t*, Fig. 94). These appear to replace the swarm-spores of other seaweeds, and may also be compared to the conidia of certain fungi; they are destitute of cilia, and are, as a consequence, not locomotive.

308. The sexual organs consist of carpogones and antherids. The latter are situated singly or in groups on the ends of branches (*A* and *B*, *a*, *a*, Fig. 95). The antherozoids are small round bodies which are destitute of cilia

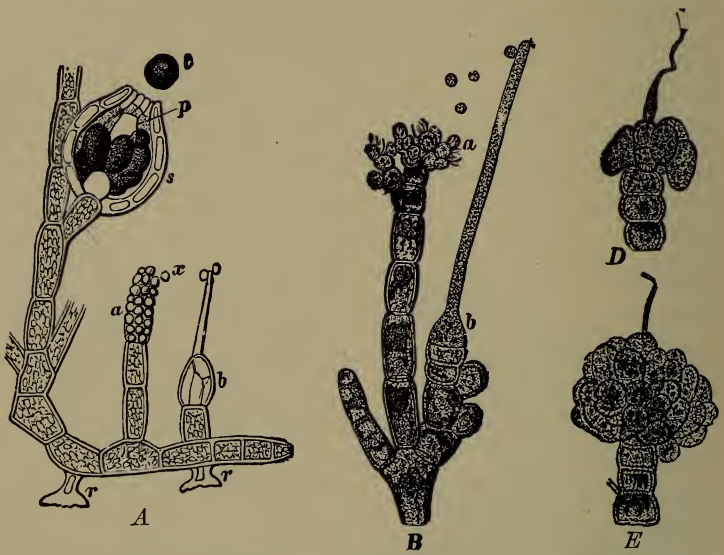


FIG. 95.—Sexual reproduction of Red Seaweeds. *A* (Lejolisia): *a*, antherid; *x*, antherozoids; *b*, carpogone, with antherozoids attached to the trichogyne; *s*, section of ripe spore-fruit, from which a spore (fruit-spore) is escaping. *B* (Nemalion): *a*, antherid, and antherozoids; *b*, carpogone. *D* and *E*, development of spore-fruit. Magnified 150 times.

(*A*, *x*, Fig. 95), and are carried about by currents of water, and in this way brought to the carpogones.

309. The carpogones are somewhat variable as to their complexity, being much more simple in the lower orders than in the higher. In some cases (Nemalion) the carpo-

gone (*B*, *b*, Fig. 95) is thickened below, and elongated above into the trichogyne, which differs from that in Coleochæte in not being open at the top.

310. When the antherozoids are set free from the antheridis, they attach themselves to the trichogyne, as shown in Fig. 95. The result of this contact of the antherozoids with the trichogyne is the fertilization of the carpogone, which immediately enlarges and at the same time undergoes division into many cells, which grow into short, crowded branches, bearing a spore at the end of each (*D* and *E*, Fig. 95). This growth, which includes the spores and the short branches which bear them, and which resulted from the fertilization of the carpogone, is the spore-fruit (*sporocarp*) of these plants. In the genus under consideration the spore-fruit is a comparatively simple growth, as compared with the degree of complexity it reaches in some other orders of this class.

311. In some other cases (Lejolisia, etc.) the carpogone, before fertilization, consists of several cells (*A*, *b*, Fig. 95). Upon fertilization taking place the outer cells of the carpogone divide, and develop into articulated branches which lie side by side and form a more or less spherical envelope, the so-called "pericarp." In the mean time the central cell of the carpogone produces outgrowths or short branches which eventually bear spores, occupying the cavity of the pericarp (*A*, *s*, Fig. 95). The spore-fruit here consists of a fertile part which bears spores, and a sterile part which serves as a protection or covering. In technical works the spore-fruit is called a "cystocarp."

Practical Studies.—The Red Seaweeds include about 2000 species, all falling within the single order (11) FLORIDEÆ. There are many families, but it is unnecessary to notice them here particularly.

About one hundred species occur along the New England coast, and the number is greatly increased as we pass to the southward.

It is better for the student to study the plants of this class at the seashore, but the beginner should not fail to make a careful study of such specimens as may be accessible.

Specimens for the study of the structure should be preserved in alcohol or glycerine. However, much may be made out by the careful examination of dried specimens.

Red Seaweeds may often be obtained "in the rough" which can be slightly moistened and then pressed out and dried for study. Such material will often yield quite good specimens.

Good mounted microscopic specimens may sometimes be obtained showing the structure of the plant as well as of the sexual and asexual reproductive organs.

Systematic Literature.—Farlow, Marine Algæ of New England, 106–183.

Class 6. **Ascomyceteæ.** The Sac-fungi.

312. This large class includes chlorophyll-less plants which differ much in size and appearance, but which agree in producing their fruit-spores (sac-spores, or *ascospores*) in sacs (*asci*).

313. The sexual organs where known consist of carpogones and antherids, and, after fertilization, produce a spore-fruit (sporocarp) which includes the sacs and sac-spores. The most common number of sac-spores is eight in each sac; but it sometimes exceeds, and frequently falls short, of this number, there being often no more than one or two. The sacs are in many cases arranged side by side in a compact mass, forming a spore-bearing surface (the *hymenium*).

314. In addition to the sac-spores there are generally one or more other kinds of spores which are developed asexually. Some of these are doubtless to be regarded as the equivalents of the conidia of the lower groups, and will accordingly be so named here.

The Sac-fungi include 20,000 well-defined species representing six orders, with about 12,000 more whose life-history is so slightly known that they are called the "Imperfect Fungi," and temporarily grouped in three additional orders.

315. The Simple Sac-fungi (Order 12. PERISPORIACEÆ).—These plants, which are mainly parasitic, are composed of branching jointed filaments (*hyphæ*) which form a white web-like film upon the surface of the leaves and stems of their hosts. There are both sexual and asexual spores, and of the latter there are in some cases two or three different kinds, which are produced earlier than those that result from a fertilization.

316. The sexual organs and the spore-fruit resulting from the act of fertilization bear a striking resemblance to

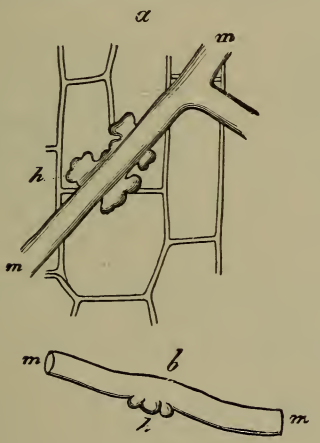


FIG. 96.

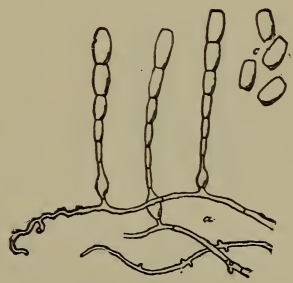


FIG. 97.

FIG. 96.—Grape-mildew (Uncinula). *a*, a piece of a vegetative hypha, *m*, *m*, upon a fragment of the epidermis of the leaf of the grape, and to which it is fastened by the suckers, *h*; *b*, hypha, with the suckers, *h*. seen in side view. Magnified 370 times.

FIG. 97.—Grass-mildew (Erysiphe communis). *a*, vegetative filaments, with a few suckers; *b*, branches bearing conidia; *c*, separated conidia. Magnified 135 times.

those of Coleochaete, the difference being such as may be accounted for by taking into consideration the aquatic

habits of the one and the aerial and parasitic or saprophytic habits of the other.

317. In the **Powdery Mildews,** which are all parasitic, the jointed filaments closely cover the leaves and other tender parts of their hosts, and draw nourishment from them by means of suckers, which project as irregular outgrowths from the side next to the epidermis (Fig. 96). These suckers apply themselves closely to the epidermal cells, and, in some cases, appear to penetrate them.

318. The crossing and branching filaments soon send up many vertical branches, in which partitions form at regular intervals. The cells thus formed are at first oblong and cylindrical, with flattened ends ; but the topmost one

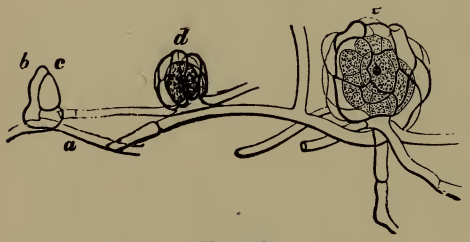


FIG. 98.

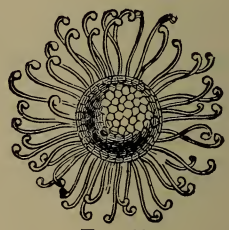


FIG. 99.

FIG. 98.—The sexual process in a Powdery Mildew (Erysiphe). *a*, jointed threads; *b*, antherid; *c*, carpogone; *d*, young spore-fruit; *e*, older spore-fruit. Magnified.

FIG. 99.—Ripe spore-fruit of Willow-mildew (Uncinula salicis). The appendages are curved or hooked. Magnified.

soon becomes rounded at its extremities, and the others follow in quick succession, thus giving rise to a row of cells, the spores, or *conidia* (Fig. 97). These fall off and germinate at once by pushing out a tube, which gives rise to a new plant.

319. The sexual process in most species takes place late in the season. Two filaments crossing each other or coming into close contact swell slightly and send out from each

a short branch; one of these becomes the carpogone (*c*, Fig. 98), and the other the antherid (*b*, Fig. 98).

320. Fertilization is effected by the direct union of protoplasm. Eight or ten branches then grow out just below the carpogone, and growing upward soon completely cover it with a cellular coat which eventually becomes hardened and turns brownish in color, constituting the pericarp of the spore-fruit (Fig. 99). In some cases it appears that there is no actual fertilization, and that the spore-fruit develops without it, the sexual organ being so much degenerated as to be functionless.

321. The carpogone inside of the pericarp gives rise, by branching, to one or more large cells filled at first with granular protoplasm, which soon forms two to eight spores (Fig. 100). Upon its outer surface the spore-fruit develops long filaments (known as *appendages*), probably for holdfasts. In some genera these terminate in hooks (Fig. 99); others are dichotomously branched; still others are needle-shaped; while many end irregularly. The spore-fruits remain during the winter upon the fallen and decaying leaves, and finally, by rupturing, permit the sacs, with the contained spores, to escape.

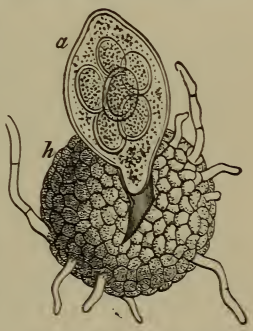


FIG. 100.—A ruptured spore-fruit of Gooseberry-mildew, showing the escaping sac, with its contained spores. Magnified about 270 times.

322. The **Herbarium-mould** (Eurotium) is a near relative of the Powdery Mildews. It is common on poorly dried specimens in the herbarium, and also on decaying fruits, wood, etc. It sends up vertical branches, which swell at the top and bear a great number of small protu-

berances (the *sterigmata, A, c, st,* Fig. 101), each of which produces a chain of conidia.

323. The sexual organs appear a little later than the conidia. The end of a branch of the plant becomes coiled into a hollow spiral (*A*, *as,* Fig. 101), which constitutes

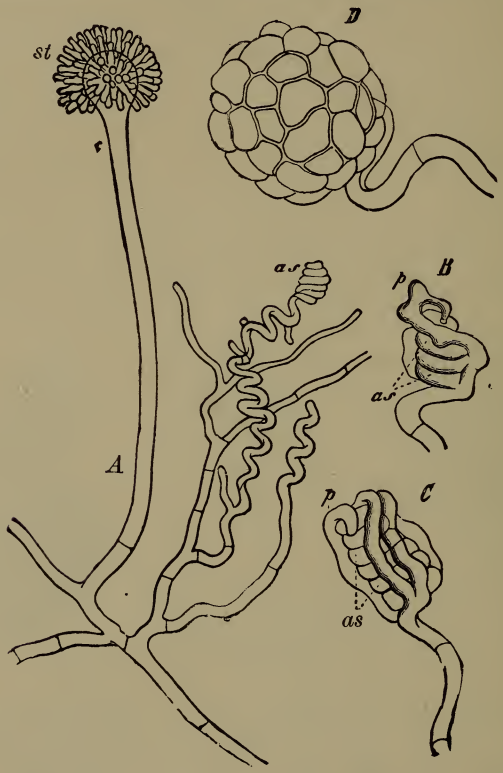


FIG. 101.—Eurotium. *A*, a portion of the plant, with erect hypha, *c*, bearing at its top a radiating cluster of sterigmata, *st*, from which the conidia have fallen ; *as*, young carpogone—below it a younger branch is beginning to coil spirally to form another carpogone. *B*, the carpogone, *as*, and the antherid, *p*. *C*, the same beginning to be surrounded by the enveloping branches which grow out from its base. *D*, spore-fruit. Highly magnified.

the carpogone. From below the spiral an antherid grows upward, and brings its apex into contact with the upper cells of the carpogone (*B,* Fig. 101).

324. After fertilization other branches grow up around the carpogone, and finally completely enclose it, as in the Mildews, described above (*C, D,* Fig. 101). In the mean time from the cells of the enclosed carpogone branches bud out, and finally produce many eight-spored sacs on their extremities; after a time the sacs are dissolved, and the spore-fruit, now of a sulphur-yellow color, contains a multitude of loose spores.

Practical Studies.—(*a*) Collect in the autumn a quantity of leaves of the lilac which are covered with a whitish mould-like growth, the Lilac-mildew (Microsphæra alni). Scrape off a bit of this Mildew after moistening with a drop of alcohol ; mount carefully, adding a little potassic hydrate. Look for conidia and suckers (haustoria). Look also for spore-fruits, which appear like minute dark dots to the naked eye. Carefully crush the spore fruits and observe the sacs (4 to 7) with their contained spores (6). Notice the beautifully branched tips of the appendages.

(*b*) Collect and study the Mildews to be found on hops (Sphærotheca castagnei), on cherry- and apple-leaves (Podosphaera oxycanthæ), on hazel- and ironwood-leaves (Phyllactinia suffulta), on willow-leaves (Uncinula salicis), on leaves and fruit of grapes (U. necator), on wild sunflowers, verbenas, etc. (Erysiphe cichoracearum), on peas, grass, anemones, buttercups, etc, (E. communis).

(*c*) Place a few slips of green twigs in an ordinary plant-press, allowing them to remain until they become (1st) mouldy (conidial state), and (2d) covered with minute yellow globular bodies (the spore-fruits). These are known as the Herbarium-mould (Eurotium herbariorum). Study as in case of the blights.

Systematic Literature.—Ellis and Everhart, North American Pyrenomycetes, 1–56. Saccardo, Sylloge Fungorum, **1** : 1–87.

325. The Truffles (Order 13. TUBEROIDEÆ) are well known from their large underground spore-fruits, which are edible. Internally there are narrow tortuous channels on whose walls sacs develop, each containing a number of spores (Fig. 102). Little is known of their round of life, and the sexual organs have not been discovered.

326. The Blue Moulds (species of Penicillium) are mem-

bers of this order, and are in reality minute truffles. The conidial stage is the common Blue Mould on decaying fruit and pastry (Fig. 103). The sexual organs resemble those

FIG. 102.

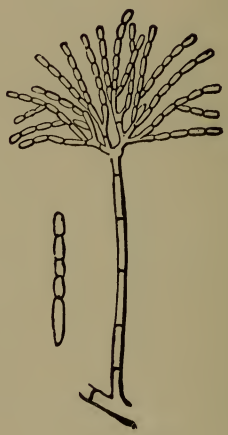


FIG. 103.

FIG. 102.—*A*, a small slice of the spore-fruit of a truffle (Tuber melanosporum), showing sacs and spores; *B*, a sac and its spores, more enlarged.
FIG. 103.—A filament of Blue Mould (Penicillium chartarum), bearing conidia. At the side is shown an isolated chain of conidia.

of the herbarium-mould, and the spore-fruit is a minute truffle-like body as large as a coarse sand-grain.

Practical Studies.—(*a*) Truffles are natives of Europe, but they may be obtained for study in our markets. Make thin cross-sections of the large spore-fruit, and examine the spores and spore-sacs.

(*b*) Blue Mould may be obtained from decaying fruit, pastry, and frequently upon ink.

Systematic Literature.—Saccardo, Sylloge Fungorum, **8** : 863–908.

327. The Black Fungi (Order 14. PYRENOMYCETEÆ).—The plants of this order are parasitic or saprophytic fila-

ments, and their spore-fruits, which are simple or compound, are usually hard and somewhat coriaceous. Of the eight families all are ordinary fungi excepting one in which the species are "Lichen"-forming.

328. A good illustration of the plants of this order is the Black Knot (Plowrightia morbosa), which attacks the plum and cherry. In the spring the parasitic filaments, which the previous year penetrated the young bark, multiply greatly, and finally break through the bark, and form a dense tissue. The knot-like mass grows rapidly, and when full-sized is usually from two or three to ten or fifteen centimetres long (.8 or 1.2 to 4. or 6. in.), and from one to three centimetres in thickness (.4 to 1.2 in.); it is solid and but slightly yielding, and is composed of filaments intermingled with an abnormal development of the bark-tissues of the host-plant.

329. The knot at this time is dark-colored, and has a velvety appearance, which is due to the fact that its surface is covered with myriads of short, jointed, vertical filaments, each of which bears one or more conidia (Fig. 104, 1). The conidia, which fall off readily, are produced until the latter part of summer, when the filaments which bear them shrivel up and disappear.

330. During the latter part of summer spore-sacs are produced, but require the greater part of winter to come to perfection. The spore-sacs grow in the cavities of minute papillæ (*perithecia*), and are intermingled with slender filaments (paraphyses, 3 and 4, Fig. 104). Each spore-sac contains eight spores, which eventually escape through a pore in the top of the sac. These spores germinate by sending out a small filament, or sometimes two (Fig. 104, 6).

331. Besides the perithecia, there are other cavities

found which much resemble them and contain other supposed reproductive bodies.

332. No sexual organs have as yet been observed. Possibly they exist in the dense tissues of the knot, and fertilization may occur in the spring or early summer, but they

FIG. 104.—Structure of Black Knot. 1, filaments bearing conidia; 2, stylospores; 3, a hollow papilla (perithecium) containing spore-sacs; 4, spore-sacs and spores, with three slender filaments (paraphyses); 5, a spore; 6, spores germinating. All much magnified.

have probably disappeared through the excessive parasitism of these plants.

333. The parasitic filaments of each year's knot generally penetrate downward some centimetres into the uninjured bark, and remain dormant there until the following spring, when they begin the growth which results in the production of a new knot, as described above.

334. To this order belongs the Ergot (a common parasite upon heads of rye), and also many of the black growths upon the bark and wood of trees. Many species produce black spots upon living leaves, while many others occur upon dead leaves and twigs.

335. The Black Fungi include a large number of exceed-

ingly injurious species; they often attack and destroy not only plants, but also insects, upon which their ravages are in many cases very great.

336. Some Black Fungi, constituting the family *Verrucariaceæ*, are parasitic upon unicellular or few-celled plants, protophytes and phycophytes, and are commonly known as "lichens." Their general structure is much like that of the lichen-forming species of the next order (par. 342 to 347).

Practical Studies.—(*a*) In early summer examine the Choke-cherry and Plum trees (wild and cultivated) for the young stages of Black Knot. Watch the development until the knot becomes velvety in appearance (about midsummer). Now make very thin cross-sections of the knot and examine for conidia. The several stages may be readily preserved in alcohol for future study.

(*b*) Late in autumn and in early winter examine the knots on the same trees. Note the young perithecia, i.e., hollow papillæ. Make very thin vertical sections through some of these. No perfect spores can be found at this time.

(*c*) Collect fresh knots in midwinter and make similar examinations, when the sacs and spores will be found.

Systematic Literature.—Ellis and Everhart, North American Pyrenomycetes, 58–758. Saccardo, Sylloge Fungorum, **1**: 88–766; **2**: 1–813.

337. The Cup-fungi (Order 15. DISCOMYCETEÆ).—The common Cup-fungus of the woods is a typical representative of this order. The familiar cup- or saucer-shaped growth is in reality the spore-fruit, while the plant itself generally grows underground. The plant consists of whitish jointed filaments which grow on or in the ground, drawing their nourishment from decaying sticks, roots, etc.

338. But little is known as to the asexual reproduction, but in some species conidia much like those in the preceding orders have been observed.

339. The sexual organs are produced by the swelling up

of the ends of certain of the filaments of the plant into globular or ovoid cells, the carpogones, each having a projection (trichogyne). From below each carpogone a slender branch grows out, and becomes the antherid (Fig. 105).

FIG. 105.—Sexual organs of a Cup-fungus (Peziza omphalodes). The two carpogones are globular; each has a curved trichogyne. The antherids are curved branches from below the carpogones. Much magnified.

340. In the few plants in which it is known fertilization is effected by contact of the antherid with the trichogyne. As a result numerous branches start out from below the carpogone, and growing upward form a dense felted mass which gradually takes on the size and form of the spore-fruit. Some of the filaments of the spore-fruit become enlarged into sacs in which spores are developed (Fig. 107), while the others (*paraphyses*) make up the sterile or protective tissue. The spore-sacs grow so that all reach the same height, and make up the inner surface of the cup (Fig. 106).

341. While the foregoing may be regarded as the typical structure of the plants of this order, it presents several modifications, the most important of which is that due to the peculiar parasitism occurring in three families which gives rise to the "lichen" structure. These have generally been regarded as constituting a separate order, but it is now known that there are "lichen-forming" plants in widely separated groups. However, since the greatest number of species occurs in this order, they may be studied best here by the beginner.

342. The Lichens are among the most interesting plants of the vegetable kingdom. They are not only often of ex-

ceeding beauty, but their structure and their mode of life are in some respects very wonderful. They abound almost everywhere—on tree-trunks, rocks, old roofs, and in many

FIG. 106.

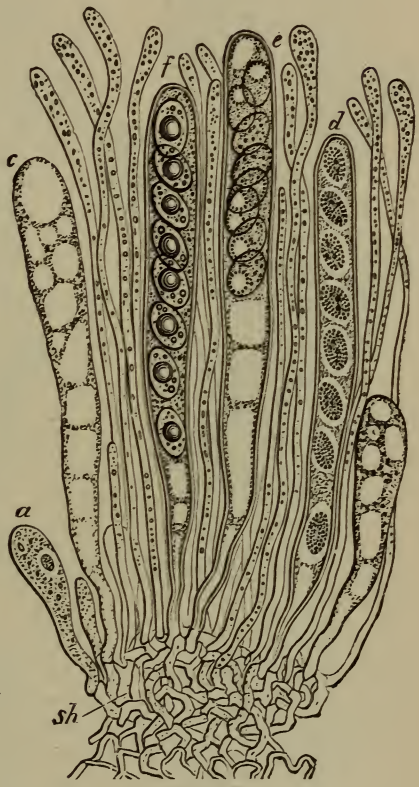


FIG. 107.

FIG. 106.—Diagrammatic vertical section of a Cup-fungus, showing position of the spore-sacs.

FIG. 107.—A few spore-sacs of a Cup-fungus (Peziza convexula), in various stages of development. *a*, youngest, to *f*, oldest. The slender filaments (paraphyses) belong to the sterile tissue. Magnified 550 times.

regions upon the ground. They are for the most part of a greenish-gray color, and hence are often called Gray Mosses. Other colors, as black, purple, yellow, and white, are also common.

343. They are all of rather small size, varying from a millimetre or so to 20 or 30 cm. in length. For the greater

FIG. 108.—*A*, a flat-growing (foliaceous) Lichen (Sticta pulmonaria); *B*, a stemmed (fruticose) Lichen (Usnea barbata); *a*, *a*, fruit-disks (apothecia). Natural size.

part the plant-body is flattish, and adherent to the surface upon which it grows (*A*, Fig. 108), but some species have more or less elongated branching stems (*B*).

344. The plant-body of a lichen is composed of jointed, branching, colorless filaments similar to those in the other families of this order, but more or less compacted together into a thallus or branching stem. They obtain their nourishment from little green protophytes or phycophytes to which the filaments attach themselves parasitically. These little hosts, which live in the midst of the moist tissues of the lichens, were until recently supposed to be parts of the lichen itself, and were called gonidia,

a term which is still in common use.

345. The spores of lichens are produced in sacs, which are similar to those of other Cup-fungi. In many common species the spore-bearing disks (called *apothecia*) are large and readily seen (Fig. 108, *A* and *B*), while in others they are small and not easily made out. In other species the spore-sacs are immersed in cavities which show only as blackish lines or dots on the surface of the lichen-body.

346 The spores germinate by sending out one or more tubes which develop directly into the ordinary filaments of the lichen-

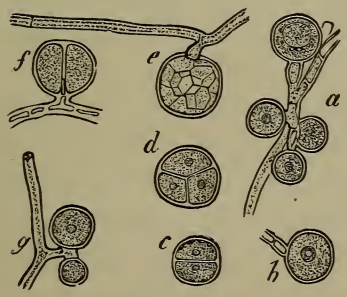


FIG. 109. FIG. 110.

FIG. 109.—Green plants (gonidia) dissected from different Lichens, showing attachment of the parasitic filaments; several are dividing. All highly magnified.

FIG. 110.—A vertical section of a common Lichen (Physcia stellaris) through a fruit-disk, showing spore-sacs at *th*, intermingled with slender filaments (paraphyses), *t*; gonidia (species of Protococcus) at *g*, *g'*; *cm*, the interlacing branching filaments, becoming harder and denser at *cc* and *h*. Much magnified.

body. Experiments have shown that these filaments will not grow for any great length of time unless they come into contact with a green plant of the proper species, to which they become attached, growing rapidly and surrounding them. On the other hand, in the moist

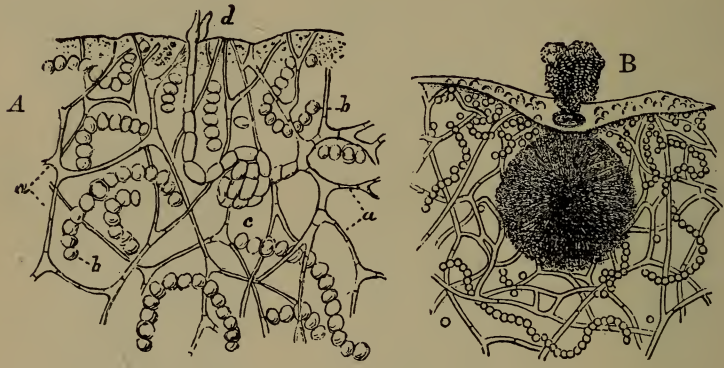


FIG. 111.—Sections of gelatinous Lichens (Collema), showing (in *A*) a carpogone, *c*, with its projection, *d*, and (in *B*) a cavity (spermogone) emitting sperm-cells (spermatia). The gonidia here (*b*, *b*) are species of Nostoc. Highly magnified.

tissues thus formed the green plants find protection and ample opportunity for growing. There is thus an association between these plants which is mutually beneficial (symbiosis). The lichen lives parasitically upon the green plants, to which it in return furnishes shelter and moisture.

347. We know very little as to the sexual organs of lichens. A few years ago Stahl discovered them in Collema, a low form of gelatinous lichens. The carpogone is a tightly coiled spiral filament, which sends up a prolongation to the surface (Fig. 111, *A*, *c*, *d*). Fertilization takes place by means of minute cells (sperm-cells, or *spermatia*), which are produced in countless numbers in cavities (*spermogones*) in the lichen-body. The sperm-cells come in

contact with the projecting filament (*trichogyne*), doubtless by means of winds, the result of which is the rapid upward growth of filaments which ultimately produce spore-sacs and spores in disks, as above described.

348. The Plum-pocket Fungus, which distorts the young plums in spring and early summer, is a greatly reduced cup-fungus (family *Gymnoascaceæ*). Here the parasite consists of delicate threads which penetrate the tissues of the plum, eventually producing on the surface poorly developed spore-sacs which are not aggregated into cups.

349. Yeast-plants. — The greatest degradation of the cup-fungus type is reached in the minute plants which occur in yeast. If a bit of yeast be placed upon a glass slip and carefully examined under high powers of the microscope, there will be seen very many small roundish or oval cells, of a pale or whitish color. They have a cell-wall, but generally the nucleus is wanting or indistinct. These little cells are Yeast-plants, and bear the name of Saccharomyces cerevisiæ.

350. They reproduce by a kind of fission, called budding. Each cell pushes out a little projection which grows larger and larger, and finally a cell-wall forms between the two, which sooner or later separate from one another (*a* and *b*, Fig. 112). Under favorable circumstances certain cells form spores internally, as in *c*, Fig. 112; and these are now regarded as spore-sacs (asci) homologous with the spore-sacs of the higher cup-fungi. Yeast-plants are, therefore, to be considered as greatly reduced sac-fungi, and they are members of what is probably the lowest family (*Saccharomycetaceæ*) of the order Discomyceteæ.

351. Yeast-plants are saprophytes, and live upon the

starch of flour. They break up the starch, and in the process liberate considerable quantities of carbon dioxide, which appears as bubbles upon the surface of the yeast. Another result of the breaking up of the starch is the formation of alcohol; hence the growth of yeast-plants in a starchy substance is always accompanied by what is known as alcoholic fermentation. The housewife and baker use yeast-plants for the carbon-dioxide gas which they evolve, to give lightness to the bread, while the brewer and distiller use the same plants for the alcohol produced by their activity.

FIG. 112. — Yeast-plants in various stages of growth, *a* and *b*. *c*, a spore-sac containing four ascospores; *d*, the four spores set free. *a* and *b* magnified 400, *c* and *d* magnified 750, times.

Practical Studies.—(*a*) Search for cup-shaped fungi, in the spring, about old hot-beds and upon well-rotted barnyard-refuse. The common Cup-fungus of an amber color (Peziza vulgaris) often to be met with in such localities is one of the best for the study of spores and spore-sacs. Make very thin sections at right angles to the inner surface. This species may be readily preserved in alcohol for future study.

(*b*) Collect the bright-red saucer-shaped plants growing in the woods upon decaying sticks and having a diameter of 1 to 4 cm. Make similar sections.

(*c*) Collect a few Morels (Morchella esculenta), and make sections at right angles to the surface of the pits which cover its upper portion for spores and spore-sacs. The Morel, which grows in the woods, is an amber- or straw-colored fungus 10 to 15 cm. high and having an egg-shaped pitted top, 3 to 6 cm. in diameter, borne upon a thick stalk, both stalk and top being usually hollow. The whole growth above ground (which is edible) is to be regarded as a spore-fruit.

(*d*) Collect fruiting specimens of the common fruticose lichen shown in Fig. 108, *B*, which grows upon branches of trees in forests. Make thin cross-sections of the stem, mount in alcohol, afterwards adding dilute potassic hydrate. Study the filaments, and their relation to the gonidia. Isolate some of the gonidia by tapping on the cover-glass, and note their resemblance to Green Slime.

(*e*) Make thin vertical sections through one of the fruiting disks, mount as above, and study spore-sacs, spores, and paraphyses.

(*f*) Collect some of the small, flat, many-lobed lichens which grow on the bark of apple-, maple-, and oak-trees, and having small blackish fruit-disks. Make careful sections of the plant-body through the fruit-disks, and study the whole structure, spores, spore-sacs, paraphyses, filaments, and gonidia. (Compare with Fig. 110.) Here also the gonidia closely resemble Green Slime.

(*g*) Collect fresh specimens of Plum Pockets, and preserve them in alcohol. Study the fungus by making very thin sections at right angles to the surface. Each spore-sac will be found to contain several rounded spores.

(*h*) Fill a strong bottle half full of active yeast, cork tightly, and keep for an hour or two in a warm room. Draw the cork and notice the violent escape of gas (carbon dioxide).

(*i*) Place a small drop of the yeast upon a glass slide, add a little water, cover with a cover-glass, tapping it down gently. After a little examination under a high power of the microscope add iodine, which will stain the starch-grains blue or purple, and the yeast-plants yellowish. Many of the latter will be found in process of budding, as in *a* and *b*, Fig. 112.

(*j*) Spread a half-teaspoonful of yeast on a fresh-cut slice of potato or carrot; cover with a tumbler or bell-jar to keep it moist; after a few days (four to eight) examine for cells which are producing spores, as in *c* and *d*, Fig. 112.

Systematic Literature.—Saccardo, Sylloge Fungorum, **8**: 3-859, 916-922. Tuckerman, Synopsis of the North American Lichens, **1**, **2**.

352. The Rusts (Order 16. UREDINEÆ) are minute, parasitic, degraded sac-fungi which grow in the tissues of higher plants. Their life-history is only imperfectly known, nothing as yet being known as to their sexual organs, if indeed they have any.

353. The common Wheat-rust (Puccinia graminis) may be taken as an illustration of the order. It is common wherever wheat is grown, and often greatly injures and sometimes entirely destroys the crop. Its round of life shows four well-marked stages, as follows: (I) In the spring clusters of minute yellowish cups break through the tissues

of the leaves of the Barberry. These cups are at first rounded masses of conidia which develop on the internal

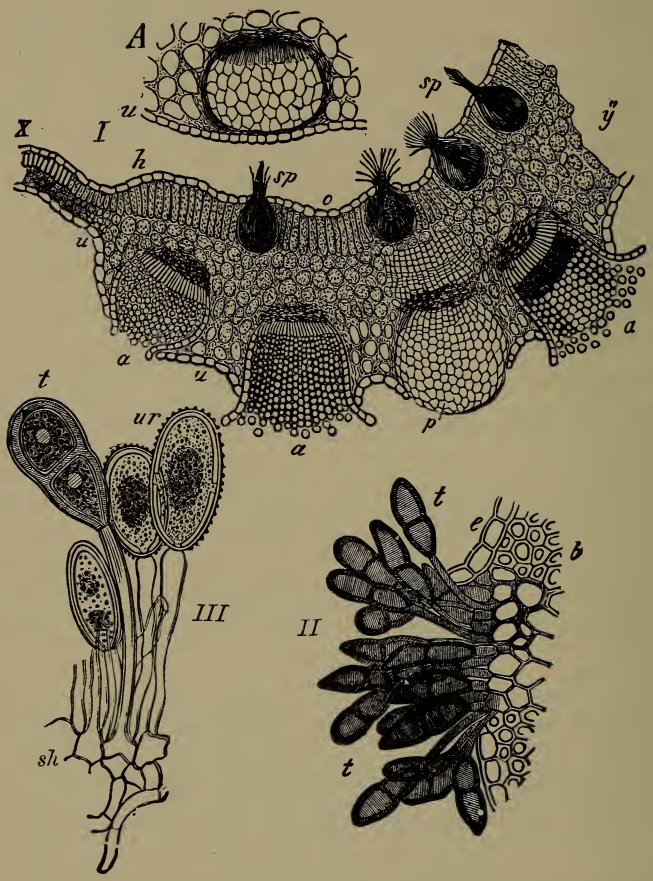


FIG. 113.—Wheat-rust (Puccinia graminis). *I*, a cross-section of a Barberry-leaf through a mass of cluster-cups; *a*, *a*, *a*, cups opened and shedding their conidia; *p*, and *A*, above, cups not yet opened; *sp*, *sp*, spermogones which produce spermatia, whose function is not known. *II*, three Red-rust spores, *ur*, on stalks; *t*, a Black-rust spore. *III*, a mass of Black-rust spores bursting through the epidermis *e*, of a leaf. All highly magnified.

parasite, and at length burst through the epidermis (Fig. 113, *A* and *I*). The conidia quickly drop out and are car-

ried away by the winds. This stage is known as the cluster-cup stage.

354. (II) The conidia falling upon a wheat-leaf germinate there and penetrate its tissues, sending parasitic filaments into the cells. After a few days, if the weather has been favorable, the parasite has grown sufficiently to begin the formation of large reddish spores (stylospores) just beneath the epidermis, which is soon ruptured, exposing the spores (Fig. 113, *II*) in reddish lines or spots upon the leaves and stems. This is the Red-rust stage, so common before wheat-harvest. These red spores fall easily, and quickly germinate (Fig. 114, *D*), producing more Red Rust and so rapidly increasing the parasite.

355. (III) Somewhat later in the season the same parasitic filaments which have been producing Red-rust spores begin to produce lines or spots of dark-colored, thick-walled, two-celled bodies constituting the Black Rust (Fig. 113, *III*). These are the "teleutospores" of the older books, but they are here regarded as spore-sacs, each containing two spores. The wall of the spore-sac fits tightly over the relatively large spores. We may well retain the name teleutospore for the spores within the sac. Being thick-walled, these spores endure the winter without injury, and when spring comes (IV) they germinate on the rotting straw and produce several minute spores, called sporids (Fig. 114, *A* and *B*). This is the fourth and last stage of the rust. The sporids fall upon Barberry-leaves and germinate (Fig. 114, *C*), giving rise to cluster-cups again.

These stages are so different in appearance that for a long time they were regarded as distinct plants, and received different names. Thus the first stage was classified as a species of Aecidium, the second as a species of Uredo, and the third as a Puccinia. We still preserve these names by sometimes calling the spores of the first

aecidiospores, and of the second uredospores, while the third name is retained as the scientific name of the genus.

The sporids cannot ordinarily produce rust directly upon wheat, probably because of the toughness of the epidermis; but it has been

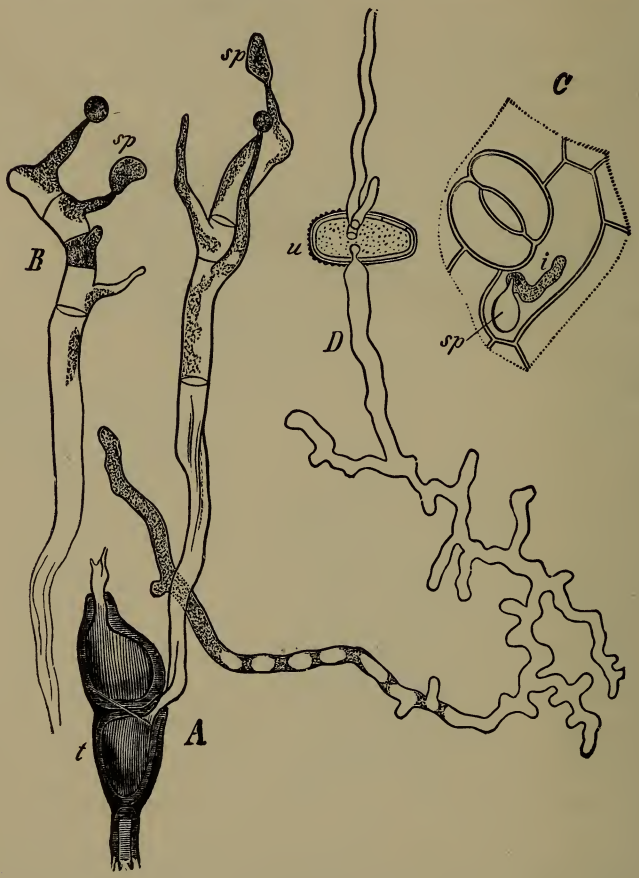


FIG. 114.—Wheat-rust. *A* and *B*, Black-rust spores germinating, and producing sporids, *sp*; *C*, fragment of a Barberry-leaf with a sporid, *sp*, germinating and penetrating the epidermis; *D*, showing manner of germination of Red-rust spore. All highly magnified.

shown that when sporids germinate upon very young leaves of wheat-seedlings they penetrate the epidermis and then soon give rise to a red-rust stage. In such cases the cluster-cup stage is omitted. Possibly the rusts upon the spring wheat, oats, and barley in the Mis-

sissippi Valley and on the Great Plains are propagated in this way. It has been shown also that on the Great Plains the red rust is perennial, blowing to the north in the spring from field to field, and blowing back to the south in the autumn. Probably this is the more common mode of propagation upon the plains.

There are many kinds of rusts, distinguished mainly by their teleutospores, which are single (Uromyces and Melampsora), in twos (Puccinia and Gymnosporangium), or several (Phragmidium). In many species the round of life is similar to that in Wheat-rust, but in others there appears to be a constant omission of certain stages. Moreover, in many species all the stages develop upon the same host-plant.

Practical Studies.—(*a*) Collect specimens of cluster-cups (from barberry, buttercups, or evening primrose, etc.); examine first under a low power without making sections. Note the cups filled with yellowish or orange conidia, (æcidiospores). Note spermogones (minute dark spots) generally on the opposite side of the leaf.

(*b*) Make very thin cross-sections through a mass of cups so as to obtain vertical sections of the cups and the spermogones. (Compare with Fig. 113, *A* and *I.*)

(*c*) In June and July collect leaves of wheat, oats, or barley, bearing lines or spots of Red Rust. First examine a few of the spores mounted in alcohol, with the subsequent addition of a little potassic hydrate. Then make very thin cross-sections through a rust-spot, and mount as before, so as to see parasitic filaments in the leaf, bearing the Red-rust spores upon little stalks. (Compare with Fig. 113, *II, ur.*)

(*d*) In July, August, or September collect stems of wheat, oats, or barley bearing lines or spots of Black Rust. Study the spores as above, and afterwards make cross-sections also (Fig. 113, *III*).

(*e*) In early spring collect and examine the Black Rust on wet stems of rotting straw. Look for germinating teleutospores and sporids (Fig. 114, *A* and *B*).

(*f*) Examine microscopically the gelatinous prolongations on "cedar-apples," and observe the teleutospores, which resemble those of Wheat-rust. "Cedar-apples," which are common in the spring on Red-cedar twigs, are in reality species of rust of the genus Gymnosporangium. Their cluster-cups occur on apple-leaves.

Systematic Literature.—Burrill, Parasitic Fungi of Illinois: Uredineæ. Saccardo, Sylloge Fungorum, 7^2: 528–882.

356. The Smuts (Order 17, USTILAGINEÆ).—The plants which compose this order are all parasites living in the tis-

sues of flowering plants. Like the Rusts, they send their parasitic threads through the tissues of their hosts, and afterwards produce spores in great abundance, which burst through the epidermis. There is a still greater simplicity of structure in the plants of the present order than in the Rusts, probably due to a greater degradation through excessive parasitism.

357. The parasitic threads of the Smuts are well defined, and consist of thick-walled, jointed, and branching filaments, which are generally of very irregular shape. They grow in the intercellular spaces and cell-cavities of their hosts, and send out suckers (*haustoria*), which penetrate the adjacent cells much as in the Mildews. The parasite generally begins its growth when the host-plant is quite young, and grows with it, spreading into its branches as they form, until it reaches the place of spore-formation. In perennial plants the parasite is perennial, reappearing year after year upon the same stems, or upon the new stems grown from the same roots; in annuals it must obtain a foothold in the young plants as they grow in the spring.

358. The life-history of the Smuts has not yet been completely made out. Two kinds of spores have been observed in many species, and the germination of the spores has been carefully studied, but the sexual organs (if any exist) have not yet been discovered.

359. The Smut of Indian corn (Ustilago maydis) is very common in autumn. The parasitic filaments are found in various parts of the host, and at last those which reach the young kernels become semi-gelatinous and form spores internally. There is much crowding and distortion of these

spore-bearing filaments, but here and there their resemblance to spore-sacs is quite evident (Fig. 115). When the spores are ripe, the gelatinous walls of the spore-sacs dissolve and, the watery portions evaporating, leave a dusty mass of black spores. The spores germinate by sending out a short fillament much as in the wheat-rust (Fig. 114, *A* and *B*), upon which minute sporids are formed. It has been found that when these sporids germinate upon the epidermis of the very young corn-plant they may penetrate it, and thus secure admission to the tissues of their host. They cannot penetrate the epidermis of older plants.

FIG. 115.—Ends of three spore-bearing filaments (spore-sacs?) of Indian-corn Smut, showing, *a*, *b*, young spores; *c*, a spore nearly ripe. Magnified 1800 times.

360. Other Smuts, as Wheat-smut or Black Blast (Ustilago tritici) of wheat, Oat-smut (U. avenæ), Barley-smut (U. hordei), and the Bunt or Stinking-smuts (Tilletia tritici and T. fœtens) of wheat, have a structure and mode of development closely resembling the foregoing.

Comparing the spores of the Smuts with those of the preceding orders, we here consider them as sac-spores (ascospores), and the mass of tissues in which they are produced, as a degraded spore-fruit. The orderly arrangement of spore-sacs so evident in the Cup-fungi is less marked in the more parasitic Black Fungi; it is scarcely noticeable in the Rusts, while in the Smuts it has entirely disappeared. As the parasitism increases the structural degradation also increases.

Practical Studies.—(*a*) Collect smutted ears of Indian corn. Mount a little of the black internal mass in water and observe the spores.

(*b*) Make very thin slices of young fresh specimens and examine for parasitic and spore-bearing filaments. The outer tissues of the distorted kernels are generally best.

(*c*) Make similar studies of the smuts of wheat, oats, or barley, which may be readily collected in June or a few days after the "heading" of the grain.

Systematic Literature.—Saccardo, Sylloge Fungorum, 7^2 : 449–527.

The Imperfect Fungi.

There are many plants (about 12,000), resembling the Sac-fungi, of which we know only the conidial stage. They have been brought together temporarily in three orders under the general name of "Imfect Fungi."

The **Spot-fungi** (Sphæropsideæ) are mostly parasitic on leaves and fruits of higher plants, producing whitish or discolored spots, and eventually developing small perithecia-like structures containing conidia. Species of Phyllosticta are common on leaves of Virginia creeper, wild grape, cottonwood, willow, pansy, peach, apple, wild cherry, elm, etc., while species of Septoria are to be found on leaves of box-elder, aster, thistle, evening primrose, wild lettuce, plum, elder, etc.

The **Black-dot Fungi** (Melanconieæ) differ from the preceding mainly in the absence of a distinct perithecium, the spores developing beneath the epidermis of the host and bursting through so as to form small dark-colored or black dots. Species of Glœosporium and Melanconium are common on leaves, fruits, and twigs. In the **Moulds** (Hyphomyceteæ) the threads grow through the stomata of the host, or penetrate the outer decaying tissues, forming mouldy patches or masses. Here are many common parasites (e.g., species of Ramularia, Cercospora, Fusicladium) and saprophytes (Monilia, Botrytis, etc.), some of which are both parasitic and saprophytic.

Systematic Literature.—Saccardo, Sylloge Fungorum, **3**, **4**.

Class 6. **Basidiomyceteæ.** The Higher Fungi.

361. The plants of this class are among the largest and finest of the fungi. They are mostly saprophytes whose abundant vegetative filaments (*mycelium*) ramify through the nourishing substance, and afterwards give rise to the spore-fruit. The spores are produced upon slender outgrowths from the ends of enlarged cells (*basidia*), usually arranged parallel to each other so as to form a spore-bearing surface (*hymenium*), which may be external (in Toad-

stools) or internal (in Puff-balls). There are about 10,000 species, which may be separated into two orders, the GASTEROMYCETEÆ and the HYMENOMYCETEÆ.

362. The Puff-balls (Order 18. GASTEROMYCETEÆ).—The plants of this order are saprophytes, whose spore-fruits

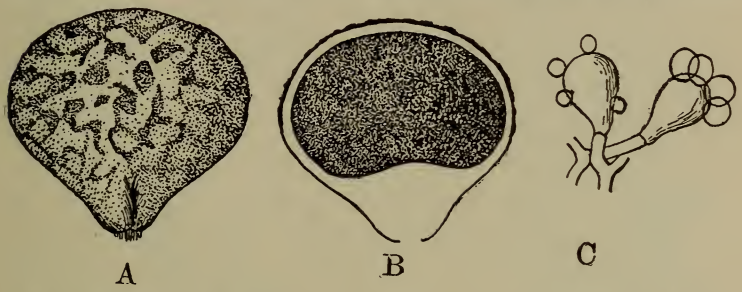


FIG. 116.—Fruit of a Puff-ball. Natural size. *A*, exterior; *B*, section showing the sterile base, with the gleba (sporiferous tissue) above. *C*, two basidia, with spores, highly magnified.

(*A*, *B*, Fig. 116) are often of large size and usually more or less globular in form. The spores are always borne in the interior of more or less regular cavities, and from these they escape by the drying and rupture of the surrounding tissues.

363. The vegetative filaments of Puff-balls penetrate the substance of decaying wood, and the soil filled with decaying organic matter. They are colorless and jointed, and usually aggregate themselves into cylindrical root-like masses. After an extended vegetative period the filaments produce upon their root-like portions small rounded bodies, the young spore-fruits, which increase rapidly in size and assume the forms characteristic of the different genera.

364. No sexual organs have yet been discovered, but analogy points to their possible existence upon the vegetative filaments just previous to the first appearance of the spore-fruits. The spore-fruits are composed of interlaced

filaments loosely arranged in the interior, and an external more compact limitary tissue forming a rind (*peridium*). The basidia develop in a portion of the interior (the gleba), the remainder being sterile (Fig. 116, *B*).

365. Many common puff-balls belong to the genus Lycoperdon, the type of the family *Lycoperdaceæ*, of which there are a good many species. The genus Calvatia contains the Giant Puff-ball (C. maxima), whose spore-fruit is sometimes 30 cm. (one foot) or more in diameter. The proper plant, that is, the vegetative portion, lives underground, obtaining its food from decaying vegetable matter. The great ball is a spore-fruit composed of innumerable filaments whose swollen extremities (basidia) bear spores (basidiospores).

FIG. 117.—Bird's-nest Fungus (Cyathus vernicosus). Natural size.

366. There are other genera, as the Earth-stars (Geaster), whose outer coat splits into a star-shaped form, the curious little Bird's-nest Fungus (Crucibulum and Cyathus, Fig. 117), fetid Stinkhorn (Ithyphallus), etc.

Practical Studies.—(*a*) Collect specimens of puff-balls in various stages of growth. Make very thin sections of the young spore-fruit, and look for the cavities lined with spore-bearing cells (basidia).

(*b*) Mount in alcohol some of the dust which escapes from a dry puff-ball. Examine with a high power, and note the spores and fragments of broken-up filaments.

(*c*) Dig up the earth under a cluster of young puff-balls, and observe the vegetative filaments. Examine some of these filaments under the microscope.

Systematic Literature.—Morgan, North American Fungi: Gasteromycetes. Saccardo, Sylloge Fungorum, 7^1 : 1–180.

367. The Toadstools (Order 19, HYMENOMYCETEÆ).—These plants in some respects are the highest of the chlorophyll-less Carpophytes. They are not only of considerable

size (ranging from one to twenty centimetres, or more, in height), but their structural complexity is so much greater

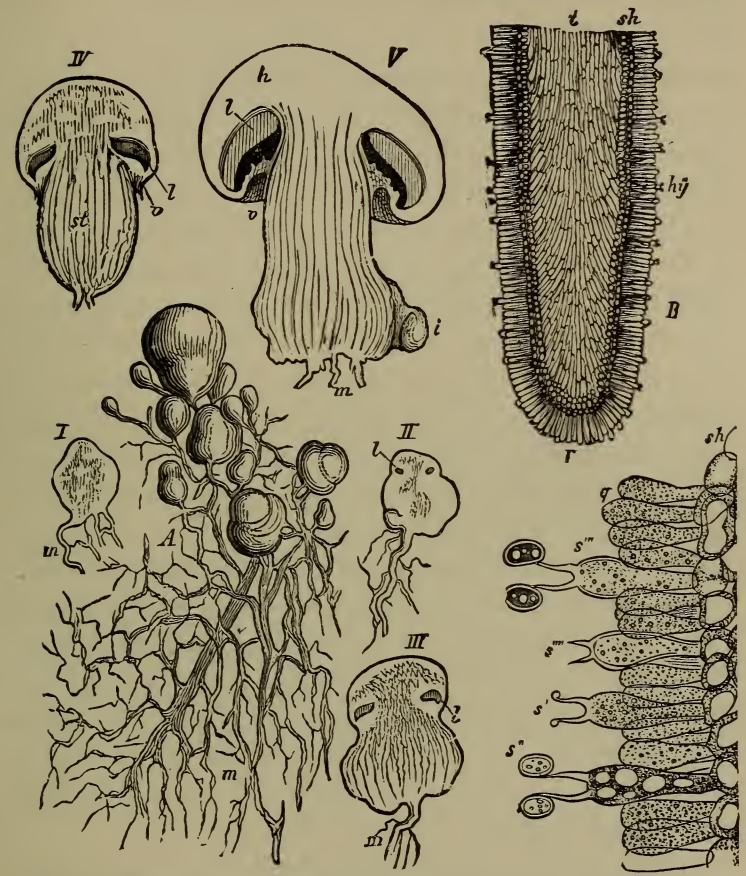


FIG. 118.—Development and structure of a Toadstool. *A*, vegetative filaments producing young spore-fruits; *I*, *II*, *III*, *IV*, *V*, sections of successive stages of spore-fruits, from very young to maturity; *l*, the gills; *v*, veil; *VI*, magnified section of a gill, showing layer of spore-bearing cells, *hy*; *VII*, greatly magnified section of part of a gill, showing layer of spore-bearing cells, with spores of different ages.

than that of the other orders that they must be regarded as the highest of the fungi. Like the Puff-balls, they produce an abundance of vegetative filaments (mycelium) un-

derground or in the substance of decaying wood. These filaments are loosely interwoven, becoming in some cases densely felted into tough masses or compacted into root-like forms (Fig. 118, *A*, *m*). Sooner or later these underground filaments produce the spore-fruits, which are mostly umbrella-shaped, as in common Toadstools and Mushrooms, or of various more or less irregular shapes, as in the Pore-fungi, Club-fungi, etc.

368. The Mushroom (Agaricus campestris) so commonly cultivated may be taken to illustrate the mode of development of the Toadstools (family *Agaricaceæ*). The vegetative filaments compose the so-called "spawn" which grows through the decaying matter from which it derives its nourishment. Upon this at length little rounded masses of filaments arise, which become larger and larger and gradually assume the size and shape of the mature spore-fruit, the Mushroom of the markets.

369. At maturity the spore-fruit of the Mushroom consists of a short thick stalk, bearing an expanded umbrella-shaped cap, beneath which are many thin radiating plates, the gills. Each gill is a mass of filaments whose enlarged end-cells (basidia) come to, and completely cover, both of its surfaces (Fig. 118, *VI* and *VII*). The basidia produce spores in the usual manner for plants of this class, that is, upon slender stalks.

370. In the Pore-fungi (*Polyporaceæ*) the spore-bearing cells line the sides of pores; in the Prickly Fungi (*Hydnaceæ*) they cover the surface of spines; while in the Ear-fungi (*Thelephoraceæ*, Stereum, etc.) they form a smooth surface.

371. But little is known as to the sexual organs. Several botanists have described such supposed organs

upon the vegetative filaments before the formation of the spore-fruit, but there are grave doubts as to the correctness of the observations, and it is the general opinion that these organs have become obsolete.

372. The vegetative filaments (mycelium) of some species of this order (as Fomes fomentarius, etc.) often form thick, tough, whitish masses of considerable extent in trees and logs, and constitute the Amadou, or German tinder of the shops.

373. We know but little as to the germination of the spores and the subsequent development of the vegetative filaments.

Practical Studies.—(*a*) Collect a few toadstools in various stages of development, securing at the same time some of the subterranean vegetative filaments. Note the appearance of the young spore-fruits, and how they develop into the mature toadstool.

(*b*) Select a mature (but not old) spore-fruit with dark-colored spores, cut away the stem, and place the top (pileus) on a sheet of white paper, with the gills down. In a few hours many spores will be found to have dropped from the gills upon the paper.

(*c*) Examine the minute structure of various parts of the spore-fruit and the vegetative filaments, and observe that they are composed of rows of cylindrical colorless cells joined end to end.

(*d*) Make very thin cross-sections of several of the gills and carefully mount in water or alcohol. Note the layer of spore-bearing cells (hymenium), with spores borne upon little stalks, as in Fig. 118, *VI* and *VII.*

Systematic Literature.—Saccardo, Sylloge Fungorum, **5**, **6**.

Class 8. **Charophyceæ.** The Stoneworts.

374. The plants of this class are small green aquatics with jointed stems bearing whorls of leaves (Fig. 119). Both stems and leaves are very simple, being often no more than a row of cells, but sometimes a cylindrical mass of cells. The sexual organs occur upon the leaves. They

consist of an ovoid carpogone and a globular antherid, which are barely visible to the naked eye.

375. The carpogone (Fig. 120, *s*) is a single cell, as in Coleochæte (p. 168), which soon becomes covered by the growth of a layer of cells from below. This covering, which here develops *before* fertilization, is homologous with the protective covering which in Coleochæte, Red Seaweeds, Powdery Mildews, etc., forms *after* fertilization has taken place.

376. The antherids (Fig. 120, *a*) are globular many-celled bodies, in the interior of which certain cells produce antherozoids. Each antherozoid is a long spiral thread of protoplasm, provided with two long cilia at one end, by means of which they swim rapidly through the water.

FIG. 119.—A Stonewort (Chara crinita). One half the natural size. (From Allen.)

377. Fertilization takes place by the antherozoids swimming down the opening at the summit of the covering cells (Fig. 120, *c*). The carpogone and its covering now become thicker-walled and constitute the proper spore-fruit. The latter soon drops off and falls to the bottom of the water, where it remains at rest for a time.

378. The spore-fruit of the Stoneworts contains, thus, but one spore. This in germination sends out a jointed filament, which eventually gives rise to a branching plant again (Fig. 119).

379. About 150 species of Stoneworts are known, all included in the single order (20) CHARACEÆ. There are

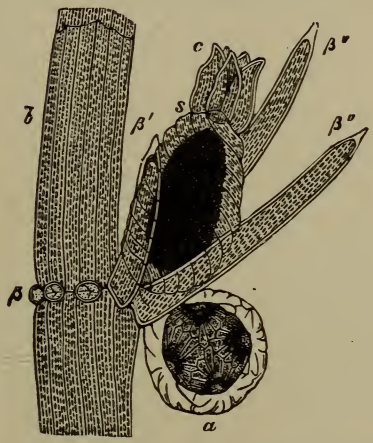


FIG. 120.—Sexual organs of a Stonewort (Chara fragilis). *a*, an antherid; *s*, spore-fruit; *c*, its crown of five cells; *b*, fragment of the leaf which bears the sexual organs; β, bracteoles. Magnified about 33 times.

two families, *Nitelleæ* and *Chareæ*, separated by the crown, which is ten-celled in the former, and five-celled in the latter. The principal genus of the first family is Nitella, and of the second Chara; each contains a dozen or more widely distributed species in this country.

Practical Studies.—(*a*) Search the sandy margins of ponds, lakes, and slow streams for Stoneworts. They are generally found in water from a few centimetres to one or two metres in depth. Preserve such specimens temporarily in water which is frequently changed, but for future use preserve in alcohol.

(*b*) Mount carefully a considerable portion of a plant, and examine its structure under a low power. Note that in some species the stem (and leaves) is composed of a row of large cells surrounded by a coat

of smaller ones. Look for the rapid movement of protoplasm which is so marked in these plants.

(*c*) Mount several spore-fruits in various stages of development. Note the covering layer of spirally coiled cells surrounding the carpogone (in young specimens) or the spore (in older specimens).

(*d*) Mount several full-grown antherids. Carefully crush them and look for antherozoids, which are produced in chains of cells.

Systematic Literature.—Allen, Characeæ of America, **1**, **2**. Flora of Nebraska, **2** : 122–128. *pl. 25–36.*

CHAPTER X.

BRANCH IV. BRYOPHYTA.

THE MOSSWORTS.

380. This branch includes plants of much greater complexity than any of the preceding. In very many cases they have distinct stems and leaves, whose tissues often show a differentiation into several varieties. In the sexual organs the cell to be fertilized (the germ-cell) is from the first enclosed in a protective layer of cells, and after fertilization it develops into a complex spore-fruit.

381. The life-cycle of the Mossworts includes a marked alternation of generations. The immediate product of the fertilization of a germ-cell is not a thalloid or leafy plant like that which bears the sexual organs, but, on the contrary, it is a many-celled leafless structure, spherical or approximately cylindrical, which eventually produces spores. The plant which produces the sexual organs is the sexual plant (*gametophore* or gametophyte) while that which prouces the spores is the asexual plant (*sporophore* or sporophyte).

382. Mossworts are all chlorophyll-bearing plants, and none are parasitic or saprophytic. They are of small size, rarely exceeding ten or fifteen centimetres in height. They generally prefer moist situations upon the ground, or on the sides of trees or rocks. A few are aquatic. Two classes may be distinguished, as follows :

Mostly thalloid creeping plants, usually with splitting spore-fruits, and having elaters.....Class 9, HEPATICÆ

Leafy stems, mostly erect, with spore-fruit usually opening by a lid, and having no elaters.....Class 10, MUSCI,

Class 9. Hepaticæ. The Liverworts.

383. In the Liverworts the plant-body is for the most part either a true thallus or a thalloid structure. When there is a differentiation into stem and leaves, in most cases the plant-body has two distinct and well-marked surfaces, an upper and an under one, the latter bearing the root-hairs (rhizoids), by means of which the plant is fixed to the ground. In this class breathing-pores are found for the first time in the vegetable kingdom. They are of very simple structure (Fig. 121).

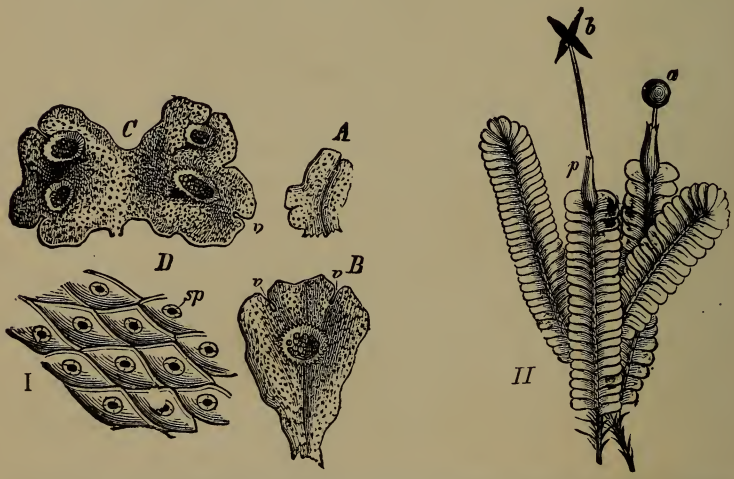


Fig. 121.—*I*, a thalloid Liverwort; *B* and *C*, showing brood-cups, natural size; *D*, enlarged to show breathing-pores. *II*, a leafy-stemmed Liverwort; *a*, unripe, and *b*, ripened and split, spore-fruit.

384. The leaves, when present, are usually in two rows (sometimes three), and are either opposite or alternate. The tissues of the plant-body show a little differentiation; the leaves, however, have no midrib or other veins, and consist of a single layer of cells. The development of the stem is always from a single apical cell, which repeatedly divides.

385. The asexual reproduction of Liverworts takes place by means of peculiar bodies, the brood-cells or brood-masses ("gemmæ"), so frequently to be seen in the common Liverwort (Marchantia polymorpha). In the latter plant they are little stalked masses of cells in small cups 4 to 6 millimetres ($\frac{1}{4}$ inch) in diameter (*B* and *C*, Fig. 121). They are in reality hairs (trichomes) whose upper cells have repeatedly divided so as to form flattish masses. When these fall off, they grow directly into new plants.

386. The antherids of Liverworts are more or less globular, stalked bodies (Fig. 122, *C*), usually immersed in little depressions in the plant-body. They are to be regarded as hairs (trichomes) whose end cells have become greatly in-

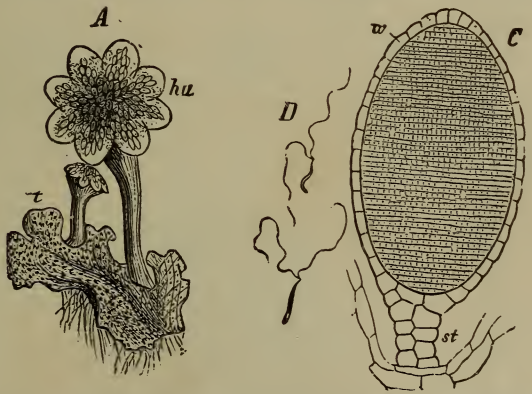


FIG. 122.—*A*, a portion of common Liverwort (Marchantia polymorpha), with two male branches, *hu*, in which antherids are borne; *C*, an antherid, magnified; *D*, two antherozoids, greatly magnified.

creased in number. There is an outer layer of cells surrounding a great number of interior thin-walled cells, the sperm-cells, each of which contains an antherozoid.

In the common Liverwort (Marchantia polymorpha) the antherids are produced in the broadly expanded disks of special branches (Fig. 122, *A*). The antherozoids are

spiral threads of protoplasm, each provided with two cilia (Fig. 122, *D*).

387. The female organ of Liverworts is called an arche-

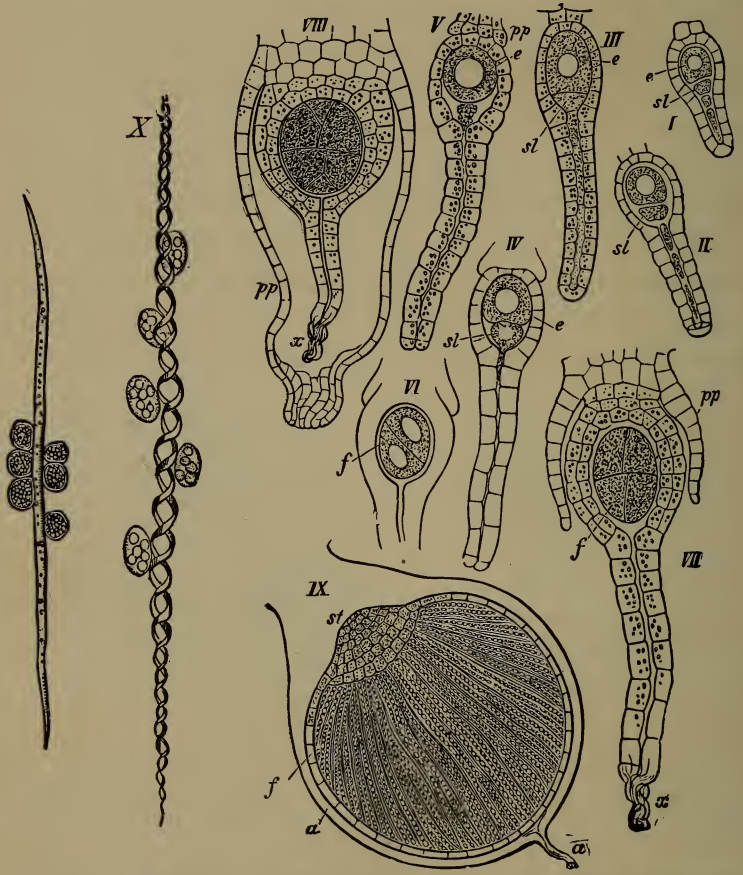


FIG. 123.—Archegones of the common Liverwort in various stages of development, *I* to *V*; *e*, germ-cell. *VI*, fertilized germ-cell, *f*, divided once. *VII* and *VIII*, further development of germ-cell; *pp*, the perianth in various stages. *IX*, germ-cell now developed into a spore-fruit, *f*, filled with spores and elaters; *a*, the greatly distended wall of the archegone. *X*, immature and mature elaters and spores. All magnified.

gonium, or archegone. It bears some resemblance to the corresponding organ in the Stoneworts (p. 203), and, like it, has an internal cell (the germ-cell) to be fertilized, sur-

rounded by an envelope of protective cells (Fig. 123, *I–V*). The archegones of the common Liverwort are clustered upon special branches a few centimetres in height. These branches expand into lobed disks at the top, and beneath these the archegones appear. They grow out as trichomes, and finally consist of a rounded cell (germ-cell) enclosed in a flask-shaped vessel (Fig. 123).

388. Fertilization takes place in wet weather by the antherozoids swimming to and down the open neck of the archegone. As a consequence the germ-cell begins dividing, and finally develops into a spore-fruit containing many spores, intermixed with spiral threads called elaters. The use of the latter appears to be to aid in the dispersion of the spores (Fig. 123, *X*).

389. In most cases the spore-fruits split open to permit the escape of the spores, which soon germinate and produce a thalloid mass; this develops directly into a new plant in the lower forms, and in the higher soon begins the development of a stem and leaves.

390. There are about 3000 species of Liverworts, distributed among three orders, viz.: (1) the Liverworts proper (Order 21, MARCHANTIACEÆ), terrestrial thalloid plants, including the common Liverwort (Marchantia polymorpha) and the Great Liverwort (Conocephalus conicus), both large, flat, branching plants growing in moist places about springs, brooks, ditches, etc.; (2) the Scale-mosses (Order 22, JUNGERMANNIACEÆ, Fig. 121, *II*), mostly leafy creeping plants growing on moist earth, rocks, and tree-trunks; (3) the Horned Liverworts (Order

FIG. 124.—A Horned Liverwort (Anthoceros lævis), natural size, with spore-fruits, *K*, *K*, splitting open.

23, ANTHOCEROTACEÆ), which are terrestrial thalloid plants with slender spore-fruits (Fig. 124).

Practical Studies.—(*a*) Collect specimens of the common Liverwort, which may be found in fruit in midsummer. Note that one plant produces the male branches, which have flat disks, and another produces the female branches, which have lobed disks. Note the brood-cups, with contained brood-masses (gemmæ).

(*b*) Examine the upper surface of a plant with a low power of the microscope, and note the round breathing-pores. Next strip off some of the epidermis, mount in alcohol, and study with a high power.

(*c*) Make longitudinal sections of the plant through its thickened central rib, and observe the elongated cells, which foreshadow fibro-vascular bundles.

(*d*) Make vertical sections of the male disk, mount in water, and study the antherids (Fig. 122, *C*). By repeated trials antherozoids may be seen.

(*e*) Make similar sections of the female disk, and study archegones. By taking older specimens the spore-fruits, spores, and elaters may be studied. For the latter, mount in alcohol and afterward add a little potassic hydrate.

(*f*) Examine the bark of trees for small brownish Scale-mosses. Mount a bit of one in alcohol, afterwards adding potassic hydrate, and study as a specimen of a leafy Liverwort. In the spring the minute splitting spore-fruits may readily be found.

Systematic Literature.—Underwood, Descriptive Catalogue of the North American Hepaticæ. Gray, Manual of Botany, 702–732. *pl. 22–25* (6th edition).

CLASS 10. **MUSCI.** THE MOSSES.

391. The adult plant-body in this class is always a leafy stem, which is rarely bilateral. It is fixed to the soil or other support by root-hairs (rhizoids) which grow out from the sides of the stem, but there are no true roots. The leaves are usually composed of a single layer of cells, and sometimes have a midrib.

392. The tissues of the Mosses present a considerable advance upon those of the Liverworts. In the stem there is frequently a bundle of very narrow thin-walled cells, which in some species become considerably thickened. In a few

cases there have been observed bundles of thin-walled cells extending from the leaves to the bundle in the stem. It cannot be doubted, then, that the Mosses possess rudimentary fibro-vascular bundles. As in liverworts, the tissues of mosses develop from a single apical cell. Breathing-pores resembling those of the higher plants occur on the spore-fruits; they are not found upon the leaves or stems.

393. Mosses, for the most part, grow upon moist earth or rocks, or upon the sides of trees ; comparatively few are aquatic. They range in size from less than a millimetre to many centimetres in length, the most common height being from two to four centimetres. They are all chlorophyll-bearing plants, and are generally of a bright-green color; occasionally, however, they are whitish or brownish.

FIG. 125.—*A*, an antherid of a Moss ruptured, showing the mass of sperm-cells, *a*, magnified 350 times; *b*, a sperm-cell, magnified 800 times, showing antherozoid, which at *c* is free.

394. The reproduction of mosses is mainly sexual, but often brood-masses are found resembling those of liverworts. The sexual organs develop either upon the end of the stem, within flower-like rosettes of leaves, or in the axils of the leaves.

The antherids are club-shaped or globose trichomes (Fig. 125), whose interior cells (sperm-cells) produce antherozoids. The sperm-cells, when mature, escape from the antherid through a rent in its wall. Each sperm-cell contains one spirally coiled antherozoid, which,

when set free, swims by means of its two long cilia (Fig. 125, *c*).

395. The archegones are elongated flask-shaped bodies with a swelling base and a long slender neck. At matu-

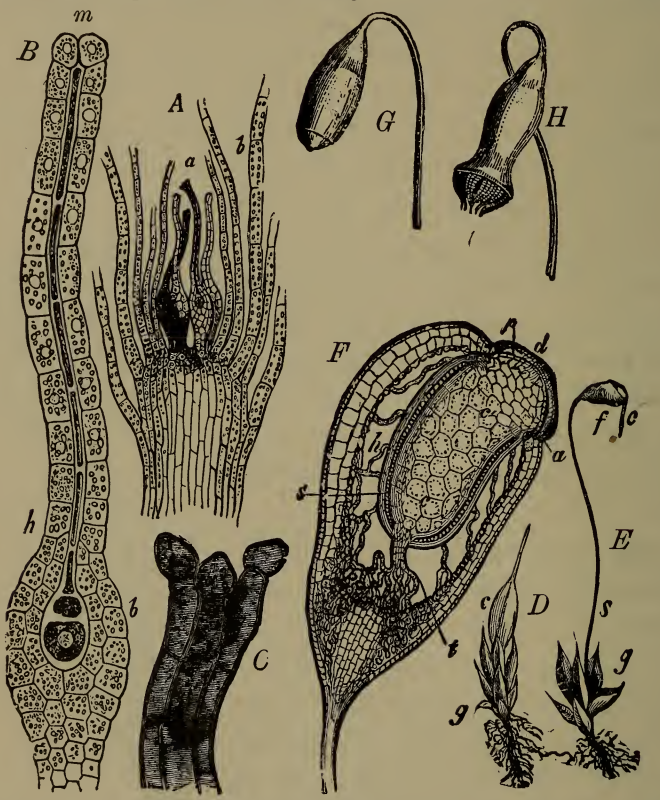


FIG. 126.—*A*, several archegones at the apex of a Moss-stem; *B*, an archegone more enlarged, showing germ-cell at *b*; *C*, apex of archegone at maturity; *D*, a Moss-plant with young spore-fruit; *E*, the same with mature spore-fruit, showing its stalk, *s*, spore-case, *f*, and the remains of the old archegone, *c* (the calyptra); *F*, vertical section of the spore-case, showing structure; *s*, the spore-bearing layer; *d*, the lid; *G*, a ripe spore-case; *H*, spore-case after the lid has fallen off, showing the teeth. All magnified.

rity the neck has an open channel from its apex to the base, where there is a rounded germ-cell (Fig. 126). In some mosses the antherids and archegones are intermixed in the

same "flower," but in other cases they occur upon different parts of the same plant (monœcious) or even upon different plants (dicœcious).

396. The act of fertilization requires water; but as the antherozoids are very minute, a dewdrop may be sufficient. The antherozoids swim to the open neck of the archegone, down which they pass to the germ-cell. The germ-cell now begins to divide rapidly, growing upward and eventually forming the spore-fruit. In most mosses the spore-fruit is narrow and elongated below, forming a stalk which supports its upper spore-bearing part (the capsule or spore-case).

397. The spore-case, when ripe, usually opens by a lid which falls off, leaving a round opening, generally fringed with many teeth (Fig. 126, *G* and *H*). In most species as the spore-fruit elongates it carries up the remains of the distended archegone as a little cap (calyptra) (Fig. 126, *E*, *c*).

398. The spores, which are round or angular cells containing protoplasm, chlorophyll-granules, oil-drops, etc., germinate quickly upon moist soil. Each spore protrudes a tubular filament, which develops into a conferva-like branching growth of green cells, called the protonema (Fig. 127). Upon this buds are eventually produced from which spring up the leafy stems, thus completing the round of life.

399. There are four orders of Mosses, including about 4500 species, as follows: (1) Order 24, ANDREÆACEÆ, composed of a few small and rare mosses. (2) The Peat-mosses (Order 25, SPHAGNACEÆ), composed of large, soft, and usually pale-colored plants, with clustered lateral branches; they inhabit bogs and swampy places, where

they form dense moist cushions, often of great extent. On account of peculiarities in the structure of their leaves they are enabled to absorb and hold large quantities of water, and for this reason they are extensively used for "packing" in the transportation of living plants. They all belong to the genus Sphagnum. (3) Order 26, ARCHIDIACEÆ, small mosses with but little development of a leafy stem, and a persistent protonema.

400. (4) The True Mosses (Order 27, BRYACEÆ) include the great majority of the species of this class. They are usually bright green (in a few genera brownish),

FIG. 127.—*A*, three spores of a Moss germinating; *B*, protonema of a Moss; *K*, a bud from which a leafy stem will develop. Highly magnified

and in most instances live upon moist ground and rocks, or upon the bark of trees; in a comparatively small number of cases the species live in the water. They are undoubtedly the highest of the class, and show a greater differentiation of tissues than any of the preceding orders. Among the more common mosses are species of Dicranum, Fissi-

dens, Polytrichum, including the well-known Hair-cap Moss (P. commune), Timmia, Bryum (Figs. 126, *G* and *H*), Mnium, Funaria (F. hygrometrica, Figs. 125, 126, *A* to *F*, and 127); Fontinalis, large floating mosses, common in brooks and rivulets; Cylindrothecium; Climacium (C. americanum is a large tree-shaped moss); Hypnum, the bog-mosses, etc.

Practical Studies.—(*a*) Collect several kinds of mosses in fruit; some of these should be of large species. Note the brownish root-hairs, the stem and leaves, the spore-fruit composed of a slender stalk bearing a spore-case, the latter in some species covered by a membranous or hairy cap (calyptra).

(*b*) Select a broad-leaved species. Mount a single leaf in water, and examine with a low power. Note that the leaf is (generally) a single layer of cells, and that the midrib (if present) is composed of elongated cells. Make cross and longitudinal sections of stems of the larger species, and note that some of the cells are elongated and fibre-like.

(*c*) Place a spore-case under the microscope and examine with a low power, noting the lid (Fig. 126, *G*). Now remove the lid and observe the teeth (Fig. 126, *H*). The teeth may be studied still better by splitting the spore-case from base to apex and then mounting in alcohol, and afterward adding potassic hydrate. In this specimen spores may be studied also.

(*d*) Split a young spore-case and examine the external surface of the lower part for breathing-pores.

(*e*) Collect a number of mosses not in fruit, showing at the apex of their stems little cup-shaped whorls of leaves. Make several vertical sections of one of these cups, and mount in water. Examine for antherids and archegones (Figs. 125 and 126). Antherozoids may sometimes be seen with a high power.

(*f*) The first stage (protonema) of a moss may be found by scraping off some of the greenish growth from a wall or cliff where young mosses are just springing up. By mounting some of this in water and washing away the dirt the branching green growth may generally be seen. (Fig. 127.)

Systematic Literature.—Lesquereux and James, Manual of the Mosses of North America

CHAPTER XI.

BRANCH V. PTERIDOPHYTA.

THE FERNWORTS.

401. The Fernworts are for the most part leafy-stemmed, root-bearing plants of considerable size, whose leaves bear spores. All are chlorophyll-bearing, and they are mostly terrestrial in habit, comparatively few being aquatic.

402. Their tissues show a high degree of development. The epidermis is distinct, and contains breathing-pores similar in form and position to those of the flowering plants. The fibro-vascular bundles are generally of the concentric type, although collateral and radial bundles occur also. The bundles generally possess tracheary and sieve tissues; the former is usually well developed, but the latter not. Fibrous tissue occurs only to a limited extent within the bundles, but it is common in the stems as thick strengthening masses. These tissues generally develop from a single cell at the apex of the stem, but in the higher orders there are groups of apical cells, as in the flowering plants.

403. The round of life of a fernwort shows an alternation of generations even more marked than that of mossworts. When a spore of a fernwort germinates, it produces a small, flat, green, liverwort-like plant upon which sexual organs arise. This is the sexual plant or gametophore. After fertilization has taken place in the sexual organs a

leafy-stemmed, long-lived plant is produced directly. This is the asexual plant, or sporophore, and upon it the spores are produced from which new individuals of the first generation may be developed.

404. The sexual plant (the "prothallium") is composed throughout of a few layers of soft tissue (parenchyma) richly supplied with chlorophyll. From its under surface root-hairs grow out into the soil. The sexual organs resemble those of the liverworts, and are antherids (producing antherozoids) and archegones. They generally develop upon the under side of the plant, and project slightly from the surface.

405. The fernworts are divisible into three classes, viz.:

Stems solid ; leaves mostly broad.....Class 11, FILICINÆ
Stems hollow, jointed ; leaves small.....Class 12, EQUISETINÆ
Stems solid ; leaves small or narrow.....Class 13, LYCOPODINÆ

CLASS 11. **FILICINÆ.** THE FERNS.

406. Here the plant-body of the sporophore consists of a solid stem, bearing roots and broadly expanded leaves, the latter usually long-stalked. The stems are mostly horizontal and underground, but in some cases they rise in the air vertically to a considerable height.

407. The leaves are in nearly all cases supplied with fibro-vascular bundles, which run as veins through the soft tissue; there is usually a prominent midrib, upon each side of which are small veins, which are *free* (i.e., running more or less parallel from the midrib to the margin) or *reticulated*. Some or all of the leaves at maturity bear spore-cases containing spores.

408. The ferns are all richly supplied with chlorophyll, and none are in any degree parasitic. Nearly all the species

are perennial, in some cases, however, dying down to the ground at the end of the summer, the underground portions alone surviving the winter.

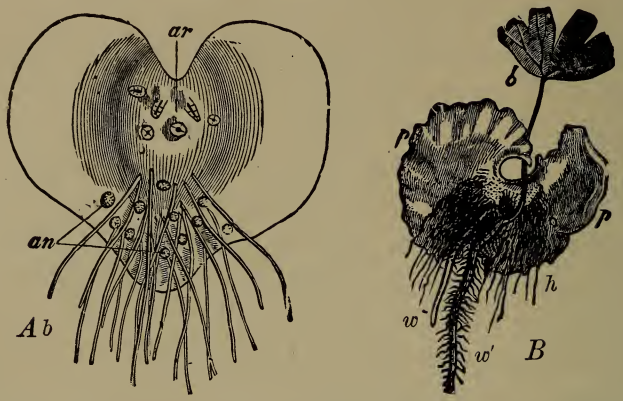


FIG. 128.—*A*, the sexual plant of a fern, under side; *b*, root-hairs; *an*, antherids; *ar*, archegones. *B*, the same after fertilization, showing the growth of the fernlet (asexual plant); *b*, its leaf; *w'*, its first root. Magnified a few times.

409. The sexual plant of ordinary ferns is small (3 to 4 mm.), somewhat heart-shaped, and generally provided with root-hairs on its under surface, by means of which it secures nourishment for its independent growth (Fig. 128, *A*). In the Pepperworts the sexual plant is so reduced as to be only a small outgrowth from the germinating spore.

410. The sexual organs develop on the under side of the gametophore (Fig. 128, *A*). The antherids are nearly globular, few-celled structures (Fig. 129, *A*) consisting of an outer layer of cells surrounding a central mass which produces the antherozoids. When mature, they rupture and permit the escape of the spiral antherozoids (Fig. 129, *C*) which swim with a rotary motion.

411. The archegones (Fig. 130) are flask-shaped organs sunken into the tissues of the plant. At first the neck is closed, but at maturity it opens down to the germ-cell

(oösphere). Fertilization takes place in water (after rains or heavy dews), the antherozoids swimming to and down

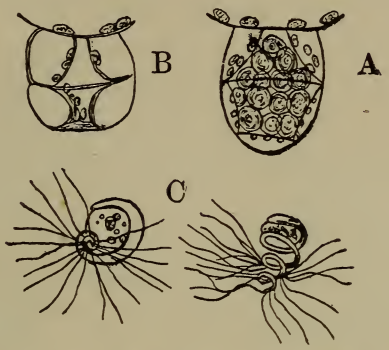


FIG. 129.—Antherids of a fern (Polypodium vulgare), × 240. A, at maturity; *B*, empty; *C*, antherozoids of same, × 540. (From Strasburger.)

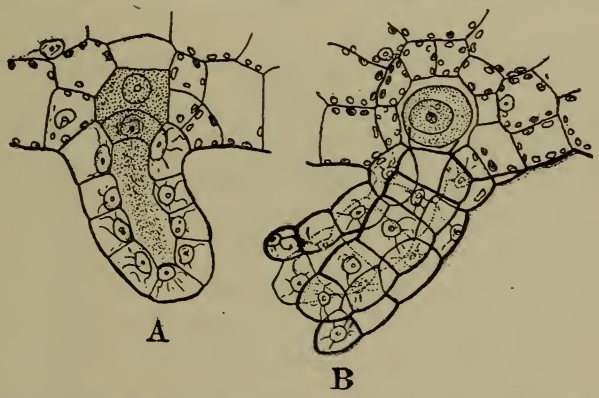


FIG. 130.—Archegones of a fern (Polypodium vulgare), × 240. *A*, before, *B*, after, opening. (From Strasburger.)

the neck of the archegone, where they unite with the germ-cell.

412. After fertilization the germ-cell divides again and again, soon producing a short stem from which a root springs at one end, while from the other the leaves arise. The latter are at first small and quite simple in structure, but those formed later are larger and more and more com-

plex in structure, until finally the full form is reached, and still later the full size. This stem, bearing leaves and roots, constitutes the asexual plant (sporophore), which is sharply contrasted with the sexual plant (gametophore) in structure, size, and duration, the latter being short-lived, small, and of simple structure, while the former is long-lived, often of large size, and of great complexity of structure.

413. The classification of ferns is based almost wholly upon the structure of the asexual plant. Four orders, including about 3500 species, are usually recognized, as follows:

414. The Adder-tongues (Order 28, OPHIOGLOSSACEÆ) include a few species of fern-like plants, in which the spores develop from cells in the tissue of the leaves. Those portions of the leaves which produce spores are much changed in size and shape (Fig. 131, *f*) and are strikingly different from the foliage segments. The spore-cases (*eusporangia*) are rounded, and split open by a simple fissure of the tissues. The leaves are of slow growth, and are straight or folded (not rolled) in the bud. The sexual plant is known in few cases, but it appears to be a rounded body, with little, if any, chlorophyll, growing a little below the surface of the ground.

Two genera, Ophioglossum, Adder-tongues proper, and Botrychium, the Moonworts, are represented in the United States by ten or eleven species.

415. The Ringless Ferns (Order 29, MARATTIACEÆ) constitute an interesting group, of mostly tropical ferns, now including but few species (20 to 25), but in geological times represented by many species. Their spore-cases are eusporangiate, i.e., they develop from internal leaf-cells,

and open by a pore or simple fissure of the tissues. The leaves, which are very large in some species, are rolled (cir-

FIG. 131.

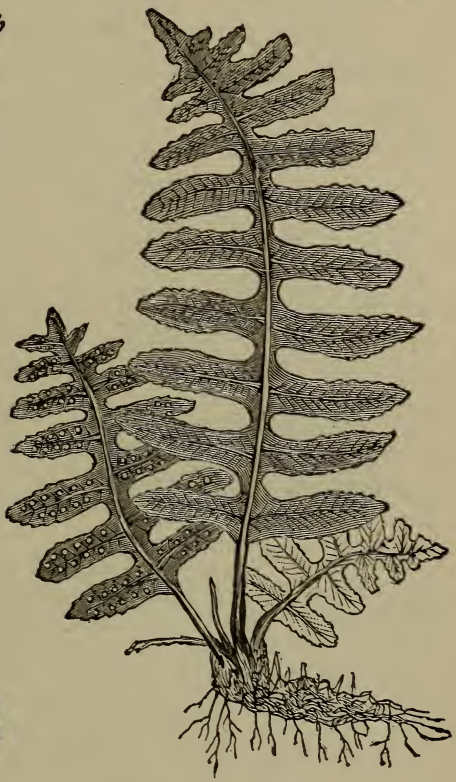


FIG. 132.

FIG. 131.—Moonwort (Botrychium lunaria), one of the Adder-tongues. *st*, the short stem bearing the divided leaf, *bs*, of which *b* is the sterile, and *f* the fertile, part.

FIG. 132.—A common Fern (Polypodium vulgare), showing the underground root-bearing stem, and the leaves, one with round spore-dots on its lower surface. Natural size.

cinate) in the bud. The most important genera are Angiopteris and Marattia. Some are cultivated in fern-houses.

416. The True Ferns (Order 30, FILICES) include very nearly all the common fern-like plants of our woodlands and hillsides. They are among the most beautiful of our land-plants, and their leaves furnish examples of a gracefulness of bearing and outline scarcely excelled in the vegetable kingdom. In temperate climates ferns are herbaceous, but in the tropics many possess an erect perennial woody stem which bears a crown of leaves upon its summit.

417. The tissues of the True Ferns are well developed. The epidermis resembles that of the flowering plants.

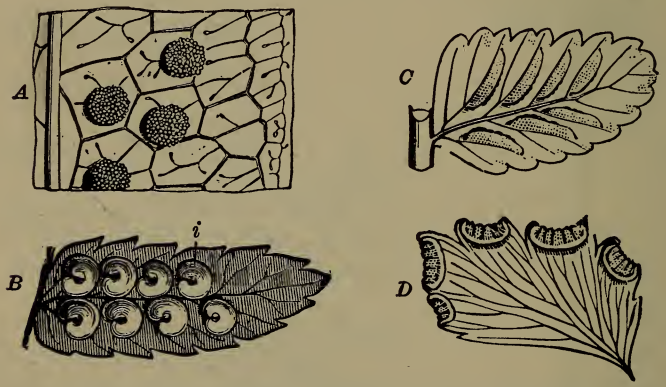


FIG. 133.—Spore-case clusters (spore-dots, or sori) of various Ferns. *A*, round and naked (Polypodium); *B*, round and covered (Aspidium); *C*, elongated and covered (Asplenium); *D*, elongated, and covered by folding of the leaf (Adiantum). All magnified. (The covering (*i*) is known as the indusium.)

Complicated fibro-vascular bundles run through the stems and extend into the leaves, where they branch extensively, forming the delicate veins which are so characteristic of fern-leaves.

418. The young leaves before expanding are coiled or rolled, so that as they grow up and open they unroll from below upwards (i.e., circinately). Upon the lower surface of some of the leaves little clusters of club-shaped hairs (trichomes) grow out, generally in connection with a fibro-

vascular bundle. The internal cells of the larger end of these hairs undergo subdivision, and thus give rise to a number of spores. The hairs are thus spore-cases (*leptosporangia*). In some ferns these clusters of spore-cases are naked (Fig. 133, *A*), while in others they are covered by a special outgrowth of the epidermis (Fig. 133, *B, C*), or by a folding of a part of the leaf (Fig. 133, *D*), etc.

419. The mature spore-case in most common ferns has a ring of thicker cells extending around it. When these become dry, they contract in such a way as to break open the spore-case and thus set the spores free.

420. The spores soon germinate, upon moist earth. The sexual plant thus produced is generally heart-shaped, flat, and green, adhering closely to the earth by its root-hairs. After some weeks or months little "seedling" ferns may be found, with one or two minute leaves. Under favorable conditions every such fernlet will give rise to a strong and long-lived fern.

Among our common ferns are the common Polypody (Polypodium vulgare, Fig. 132), the Golden Fern (Gymnogramme triangularis) of California, the Maidenhair of the North (Adiantum pedatum) and of the South (A. capillus-veneris), the common Brake (Pteris aquilina), the Spleenworts (Asplenium) of many species, the Shield-ferns (Aspidium), also of many species, the curious little Walking-leaf (Camptosorus rhizophyllus), the Bladder-fern (Cystopteris fragilis), the large Ostrich-fern (Onoclea struthiopteris), the "Flowering Ferns" (Osmunda) of several species, and, most beautiful of all, the Climbing Fern (Lygodium palmatum) of the Appalachian region.

In the Coal Period the ferns were much more numerous than at the present. Many families which flourished then are now extinct. The ferns of that period were often tree-like and of large size.

421. The Pepperworts (Order 31, HYDROPTERIDEÆ) are small aquatic or semi-aquatic plants, producing spores of two kinds, viz., small ones (microspores) which are very numerous, and large ones (macrospores) which are less

numerous. The spore-cases are enclosed in rounded "fruits" or receptacles which are modified parts of leaves.

FIG. 134.—A Pepperwort (Marsilia salvatrix, from Australia). *k*, the creeping stem, bearing the divided leaves, of which *b*, *b*, are the sterile, and *f*, *f*, the fertile, parts (the so-called fruits). One half the natural size.

422. The small spores, upon germinating, produce a slight outgrowth of a few cells (some of which develop antherids and spiral antherozoids), which is the extent of the sexual plant. The large spores likewise produce a few-celled growth, which is barely large enough to burst and protrude beyond the spore-wall. Archegones are developed upon these, and from them, after fertilization, the asexual stage of the plants is produced.

A few species of Pepperworts are sparingly found in the United States. Some have four-lobed leaves, as in the genus Marsilia (Fig. 134), of which M. quadrifolia occurs in New England, M. vestita and others in the Mississippi valley and westward; Pilularia, with filiform leaves, is represented by P. americana of the Southwest; it is 2 to 4 centimetres high, and grows in muddy places; Azolla, containing minute, moss-like, floating plants, is represented throughout the United States by A. caroliniana. These interesting plants, which should be sought for more than they have been hitherto, are doubtless much more common than we now consider them to be.

Practical Studies.—(*a*) Collect several different kinds of ferns, including the underground portions as well as the leaves. Study the fibro-vascular bundles, stony tissue, and fibrous tissue in the underground stem (Fig. 135).

(*b*) Examine the disposition of the small fibro-vascular bundles in the leaves, whether free or reticulated. Peel off a bit of epidermis from both surfaces, and study the breathing-pores.

(*c*) With a low power study the spore-dots, using top light only. The spore-cases may be easily seen and their attachment made out in this way in those cases where there is no covering to the spore-dot.

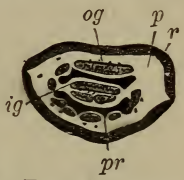


FIG. 135.—Cross-section of underground stem of a Brake (Pteris aquilina). *og*, outer ring of fibro-vascular bundles; *ig*, inner fibro-vascular bundles; *pr*, two bands of fibrous tissue (shown in black); *p*, soft tissue (parenchyma); *r*, rind of stony tissue.

(*d*) Make a vertical section through the cluster of spore-cases, and study carefully, looking for the ring of darker cells on the spore-cases.

(*e*) Sexual plants of ferns may often be found in plant-houses on or in flower-pots near ferns. They may be obtained also by sowing the fresh spores in flower-pots and keeping them in a warm damp place (a greenhouse is best). In a month or two the plants will be full grown. Collect a few of these of various sizes, carefully wash off the dirt from the under side, then mount in water, and examine the under surface for antherids and archegones (Figs. 128, *A*, 129, 130). By careful searching young fernlets may be found still attached to the sexual plant (prothallium), as in Fig. 128, *B*.

(*f*) Collect specimens of Adder-tongue or Moonwort, and compare the structure of the spore-cases with the foregoing.

(*g*) Search the borders of lakes, ponds, and slow streams for Pepperworts, especially species of Marsilia. They may probably be found in every part of the country, although they have rarely been collected.

Systematic Literature.—Underwood, Our Native Ferns and Their Allies. Gray, Manual of Botany, 678–695, *pl. 16–20* (6th edition). Hooker and Baker, Synopsis Filicum. Baker, Handbook of the Fern Allies, 134–149.

CLASS 12. **EQUISETINÆ.** THE HORSETAILS.

423. In the plants of this class the plant-body of the asexual plant consists of a hollow elongated and jointed stem, bearing whoris of narrow united leaves, which form close sheaths (*s*, Fig. 136); the stem is grooved, and is usually rough and hard from the large amount of silica deposited in the epidermis.

424. The branches, when present, are in whorls. Both the main axis and the branches are in most cases richly supplied with chlorophyll-bearing tissue; in some of the species the stems which bear the spores are destitute of chlorophyll. All the species have underground stems, which bear roots and rudimentary sheaths, and which each year send up the vegetating and spore-bearing stems.

425. The Horsetails are perennial plants. In some species the underground portions, only, persist, the aerial stems dying at the end of each year; these are called the annual-stemmed species. In other species the aerial stems also persist; the latter are hence known as perennial-stemmed.

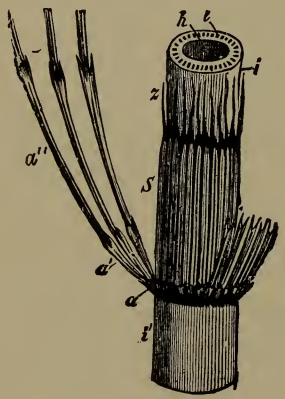


FIG. 136.

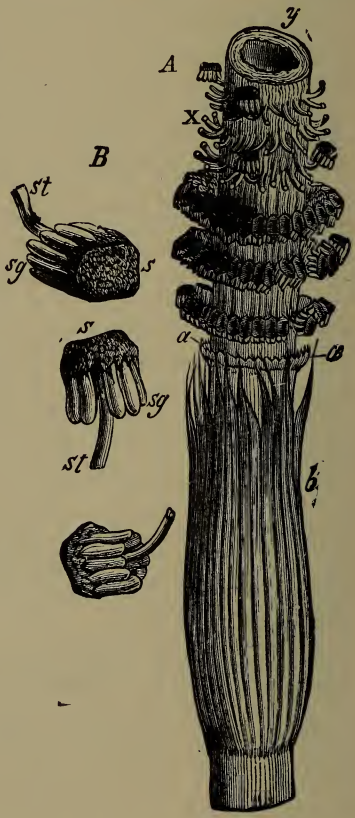


FIG. 137.

FIG. 136.—Part of a green stem of the Great Horsetail (Equisetum telmateia), showing its structure; and a whorl of united leaves, with part of a whorl of branches. Natural size.

FIG. 137.—*A*, part of an old cone of the Great Horsetail, showing three separated whorls of shield-shaped leaves; *B*, three shield-shaped leaves, slightly magnified; *st*, stalk, and *s*, expanded part of leaf; *sg*, the spore-cases.

426. The epidermal cells are mostly narrow and elongated. The breathing-pores, which are present in all the chlorophyll-bearing parts of the plant, are arranged with more or less regularity in longitudinal rows; on the stem they occur in the channels between the numerous ridges. The fibro-vascular bundles of the stem are disposed in a circle, and run parallel with each other from node to node, where they join with one another. They contain tracheary, sieve, and fibrous tissues, arranged somewhat as they are in the bundles of flowering plants.

427. The spores of Horsetails are produced in cones at the summit of the stems. The cones are composed of crowded whorls of shield-shaped leaves, each of which bears upon its under surface five to ten spore-cases (Fig. 137, *B*). The spores are spherical, and at maturity the outer wall splits spirally into four narrow filaments (*elaters*) which unroll when dry, and roll up around the spore again when moistened. Their office seems to be to aid in setting the spores free from the spore-cases. The spores germinate soon after falling upon water or moist earth, enlarging and successively dividing until a flattish irregular sexual plant (the prothallium) a few millimetres in breadth is produced. It bears sexual organs resembling those of the ferns upon its edges or lobes; in some cases both kinds of organs are on the same plant, while very commonly they are upon separate plants.

This class contains but one order (32, EQUISETACEÆ) of living plants, including a single genus and twenty species. Among the more well known are the common Horsetail (Equisetum arvense), which sends up short-lived, pale or brownish cone-bearing stems in spring, and profusely branching green stems in summer (E. telmateia, the Great Horsetail of Europe and our own Northwestern region, resembles, but is larger than, the common Horsetail); the Woodland Horsetail (E. sylvaticum), whose green cone-bearing stems branch

profusely after fruiting, and persist all summer ; and the Scouring-Rush, called also Dutch Rush (E. hiemale), with harsh green branchless stems which produce cones, and survive the winter.

In ancient geological times the Calamites and their allies constituted a distinct order (Calamarieæ) of tree-like plants ⅔ metre in thickness and ten metres in height.

Practical Studies.—(*a*) Collect in early spring a number of cone-bearing stems of the common Horsetail. Note the joints (nodes), bearing whorls of united flat leaves, and the cone, composed of whorls of shield-shaped leaves. Split the cone and stem and note that the latter is hollow, with closed nodes.

(*b*) Carefully dissect out a single shield-shaped leaf from the cone, and examine it, using a low power. Note the sac-shaped spore-cases upon the under side of the leaf. Mount some of the spores dry, using no cover-glass, and examine with the ¼-inch objective. Breathe upon the spores *very* gently to moisten them, and notice the coiling of the elaters ; observe the quick uncoiling which takes place upon the evaporation of the moisture.

(*c*) Sow a quantity of the fresh spores upon moist earth or porous pottery, covering with a bell-jar and taking every precaution to secure constant moisture. The spores will begin to germinate in a few days, when studies of successive stages of growth may be taken up. By care the mature sexual plants (prothallia) may be grown, and the antherids and archegones studied.

(*d*) Make very thin cross-sections of the stem of the common Horsetail. Note the position of the fibro-vascular bundles. Now make vertical sections of the bundles and study the tissues, using high powers.

(*e*) Study the breathing-pores on the green stems of the common Horsetail. Compare these with those of the Scouring-Rush. Study also the disposition of the chlorophyll-bearing tissue in cross-sections of both stems.

(*f*) Examine underground stems of Horsetails, and compare the structure with that of the aerial stems. Make cross-sections of the roots which are attached to these underground stems.

Systematic Literature.—Underwood, Our Native Ferns and Their Allies, 67–70. Gray, Manual of Botany, 675–677. *pl. 21* (6th edition). Baker, Handbook of the Fern Allies, 1–6.

Class 13. **Lycopodinæ.** The Lycopods.

428. The plant-body of the asexual stage consists of a solid, dichotomously branched, leafy, and generally erect

stem. The leaves are small, simple, sessile, and imbricated, and usually bear a considerable resemblance to those of Mosses. The roots are mostly slender and dichotomously branched.

429. The Lycopods are for the most part terrestrial perennials. They are usually of small size, rarely exceeding a height of 15 or 20 centimetres (6 or 8 inches).

430. The spores of the Lycopods are produced in spore-cases on the upper side of the leaves. In some of the genera the spores are of one kind; while in others they are of two kinds, large ones (macrospores) and small ones (microspores).

431. The sexual plant (prothallium) is but little known in the genera with but one kind of spore; it appears, however, to be a thickish mass of tissue, which develops underground, and bears both kinds of sexual organs. In the genera with two kinds of spores the macrospores produce small cellular growths, which project slightly through the ruptured spore-wall, and upon these several or many archegones are formed; the microspores produce very small, few-celled growths, each of which bears a single antherid, in which there are developed a few antherozoids.

There are about 480 species of Lycopods, distributed among three orders, viz.:

432. The Club-mosses (Order 33, LYCOPODIACEÆ) are terrestrial plants with many small, generally moss-like leaves covering the stems. The spore-bearing leaves are often crowded towards the summits of certain branches, in some cases forming well-marked cones (Fig. 138, *s*). The spores are all of one kind, and are borne in roundish spore-cases, which are generally single on each leaf.

The Club-mosses are common in the Appalachian region, Canada, and northwestward, and all but one of our species belong to the genus Lycopodium. Of these may be mentioned the common Club-mosses (L. clavatum and L. complanatum) and the Ground-pine (L. dendroideum), all extensively used in Christmas decorations.

433. The Little Club-mosses (Order 34, SELAGINELLEÆ) resemble the foregoing, but are generally smaller and

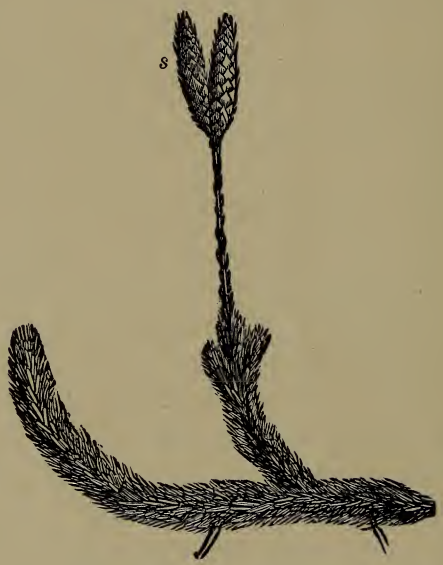


FIG. 138.—Part of a Club-moss (Lycopodium clavatum), the running, horizontal rooting stem below, with the spore-bearing cones, *s*, above. One half natural size.

more Moss-like, and have (with few exceptions) four-ranked leaves. Their spore-cases occur singly on certain more or less modified leaves, which are clustered into terminal spikes. The spores are of two kinds: the small ones, which are very numerous, are generally borne in spore-cases in the upper part of the spike, while the larger ones (macrospores) are mostly four in each spore-case in the lower part of the spike (Fig. 139).

434. The sexual plant of the Little Club-mosses is almost obliterated. When a small spore germinates, it

FIG. 139.—*A*, part of branch of a Little Club-moss (Selaginella inæquifolia), bearing a cone. Natural size. *B*, enlarged vertical section of a cone, showing spore-cases, with large and small spores.

becomes divided internally into a considerable number of cells, one of which is the remnant of the sexual stage (prothallium), while the remainder form one large antherid, each cell of which produces an antherozoid.

435. The large spore likewise produces a very small sexual plant, which in this case, however, protrudes a little from the ruptured spore-wall. Upon this several archegones develop. After fertilization the germ-cell gives rise directly to a leafy plant, which emerges from the spore-wall in a way to remind one very forcibly of the growth of a plantlet from a seed. This resemblance is made greater by the likeness of the first leaves to cotyledons (Fig. 140).

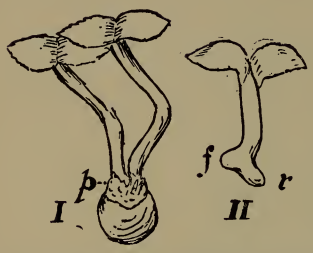


FIG. 140.—Plantlets of a Little Club-moss (Selaginella martensii), showing cotyledons. *I*, two plantlets growing from one spore; *p*, the first stage (prothallium). *II*, a plantlet separated from the spore; *r*, root; *f*, a structure called the "foot." Magnified.

But one genus, Selaginella (Family *Selaginellaceæ*) is known in this order. It contains 334 species, most of which are tropical. Two only (viz , S. rupestris and S. apus) are common throughout the United States, although six others are indigenous. Several exotic species are commonly cultivated in plant-houses.

436. The Quillworts (Order 35, ISOËTACEÆ) are small grass-like plants, with narrow leaves growing from short, thick, tuber-like stems. They grow in water or muddy places. Their spores, which are of two kinds, are produced in spore-cases on the upper surface of the leaf-bases. In their germination, and the development of their sexual organs, they resemble the plants of the previous order.

Some recent botanists have suggested that the Quillworts are more nearly related to the ferns (*Filicinæ*) than to the Lycopods, but this is probably an error. The Quillworts are all of one genus, Isoëtes, of which there are in the United States seventeen species.

Fossil Lycopods.—Two orders of Lycopods once existed, containing large trees, which appear to have been very abundant. The Lepidodendrids (Order Lepidodendraceæ) were a metre (3 to 4 feet) thick

and 15 to 20 metres (45 to 60 feet) high, and seem to have had the general appearance of the Club-mosses. The Sigillarids (Order Sigillariaceæ) appear to have been trees 30 or more metres (100 feet) in height and 1½ metres (4 to 5 feet) in diameter. Both produced two kinds of spores, showing their relationship to the Little Club-mosses and the Quillworts. Although very abundant in the Coal Period, they have long since become entirely extinct.

Practical Studies.—(*a*) Secure a few fresh or alcoholic specimens of various kinds of Lycopods in fruit. The Little Club-mosses may be readily obtained in plant-houses. Make cross-sections of the stems and study the fibro-vascular bundles, which in Lycopodium are imbedded in a thick mass of fibrous tissue. Examine the leaves, noting the small fibro-vascular bundle in the midrib. Study the epidermis, which contains numerous breathing-pores.

(*b*) Carefully dissect out from the fruiting cone of a Little Club-moss several spore-cases, the lower ones with four large spores, the upper with many small spores. Examine in like manner a cone of Lycopodium, in which but one kind of spore will be found.

(*c*) Search the borders of lakes, ponds, ditches, and slow streams for Quillworts, which may be at once distinguished from grasses, rushes, etc., by the spore-cases on the bases of the leaves. Although they are rarely collected, they may doubtless be found in almost every locality in the United States.

Systematic Literature.—Underwood, Our Native Ferns and Their Allies, 116–125. Gray, Manual of Botany, 695–700. *pl. 21* (6th edition). Baker, Handbook of the Fern Allies, 7–134.

CHAPTER XII.

BRANCH VI. ANTHOPHYTA (Spermatophyta, Phanerogamia).

THE FLOWERING PLANTS.

437. In this great group we find the highest development of the plant-body, its tissues, and organs of reproduction. They are the most complex in structure, and the most difficult to fully understand, of all the plants in the vegetable kingdom.

438. The plant-body of the sporophore is composed of roots, stems, and leaves, generally well developed. Frequently these members of the plant-body are more or less branched, giving rise to extensive branching root-systems, branching stems, and branching leaves. Hairs (trichomes) of various forms may occur upon all parts of the plant.

439. By far the greater number of flowering plants are chlorophyll-bearing, comparatively few only being parasitic or saprophytic. They range from minute plants one or two centimetres in height, and living but a few days or weeks, to enormous trees, which continue to grow for many hundred years, and attain a height of a hundred metres or more.

440. The tissues are generally well developed in flowering plants. The epidermis, which is copiously supplied with breathing-pores, consists of one or (rarely) more layers of cells, whose external walls are generally somewhat thickened, and whose cell-contents rarely contain chlorophyll.

441. The fibro-vascular bundles are of the collateral form, the only exception being the first-formed bundle in the root, which is of the radial type. The bundles are symmetrically arranged in the stem, through which they run nearly parallel to each other, and extend into the leaves; a few, however, have no connection with the leaves.

442. All the kinds of tissues, with the exception of thick-angled tissue, may occur in the bundles; but they are mainly made up of tracheary, sieve, and fibrous tissues. In the larger perennials, as the trees, the great mass of tissue in the woody stems is principally made up of the tracheary and fibrous tissues of the fibro-vascular bundles. In succulent organs and the stems and leaves of water-plants, the bundles are usually smaller and more simple, being sometimes reduced to a thread of tracheary or sieve tissue.

443. Of the remaining tissues soft tissue, in its various forms, is by far the most common. The hypodermal portions are frequently composed of thick-angled or stony tissue. Milk-tissue is common in certain families.

444. The organs of reproduction in all flowering plants are modifications of the type found in the higher Fern-worts. The leafy plant produces two kinds of cells, answering to the microspores and macrospores we have lately studied. Moreover, these cells are produced, as in Fern-worts, upon more or less modified leaves.

445. The microspores, commonly called pollen-cells, develop in great numbers within sac-like enlargements (microsporangia or anthers) upon certain modified leaves (microsporophylls or stamens). They are set free by the breaking of the sac, and are borne away by the winds, by insects, or other means.

446. The macrospores are likewise produced within outgrowths (macrosporangia or ovules) upon certain modified leaves. Only a few are produced in each outgrowth, and of these rarely more than one become fully developed. Moreover, the macrospores (here commonly called embryo-sacs) never become free, but always remain within the macrosporangium.

447. We have seen that in the higher Fernworts the parts of the plant-body bearing the spores are considerably modified, often forming cones. In the flowering plants this modification is carried still further, giving us in the lower orders such structures as the *cones* of pines, etc., and in the higher orders the many varied and beautiful forms of *flowers*.

448. The macrospore produces a sexual plant (gametophore or prothallium) and one or more archegones, as in the higher Lycopods. The archegones are usually much simplified, and in the higher plants they consist of little more than the germ-cells. The prothallium for the most part does not develop until after the germ-cell has reached maturity. It is a belated growth; having lost nearly all of its former usefulness as a supporting and nourishing tissue for the sexual organs, its development is more or less retarded.

449. Fertilization of the germ-cell takes place essentially as in plants of a lower grade. When the pollen-cell germinates, it forms in a few cases a several-celled sexual plant (prothallium), reminding us again of the higher Lycopods. More commonly even this feeble growth of a prothallium can hardly be detected. In either case the pollen-cell develops a tubular filament, sometimes of great length. If,

now, such a germinating pollen-cell happens to be favorably placed near to an ovule, the pollen-tube may penetrate it and come in contact with the germ-cell. The nucleus of the tube then unites with that of the germ-cell, and fertilization is complete.

450. The fertilized germ-cell soon begins growing and dividing, producing in a short time a many-celled body—the embryo-plant. The embryo during its growth is nourished by the surrounding cells of the prothallium, here called the endosperm. While the embryo has been growing the covering of the ovule (one or two cellular coats) becomes gradually harder and firmer; finally the growth of the embryo stops, and the ovule containing it separates from its supporting leaf as a ripe *seed*.

451. After a longer or shorter period of rest the little plant in the seed resumes its growth, the necessary conditions being the proper heat and moisture. It is at first quite simple, consisting of a little root and stem and a few small leaves, but with the development of each succeeding leaf it becomes more like the adult plant.

The flowering plants are separated into two classes, as follows:

Ovules on an open leaf.....Class 14, GYMNOSPERMÆ
Ovules enclosed within a closed leaf,
Class 15, ANGIOSPERMÆ

CLASS 14. GYMNOSPERMÆ. THE GYMNOSPERMS.

452. These are plants with solid stems, which bear in most cases small, simple, narrow leaves with parallel veins. Most of them are large trees, and all are terrestrial and chlorophyll-bearing, none being in any wise parasitic. Common examples are the pines, spruces, firs, etc.

453. The general structure of the reproductive organs may be understood from a study of those of the pines.

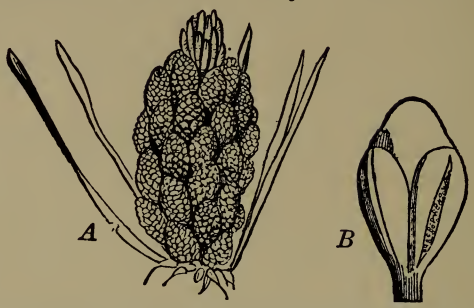


FIG. 141.—A cluster of staminate cones or flowers. *A*, of a Pine (Pinus sylvestris), with a detached stamen. Natural size. *B*, showing the two pollen-sacs. Considerably magnified.

The pollen-bearing flowers—staminate flowers, as they are generally called—are loose cones generally crowded into considerable clusters. Each cone consists of a stem upon which are many flattish stamens, each bearing two pollen-sacs (Fig. 141).

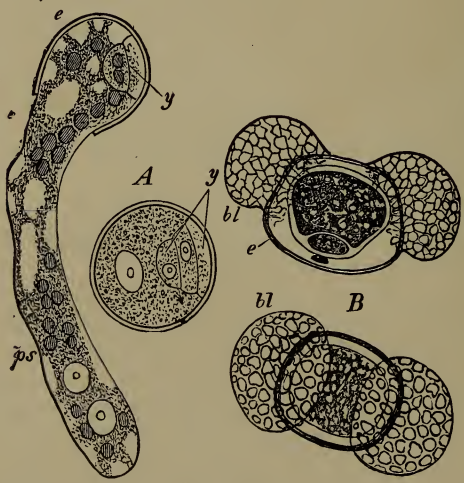


FIG. 142.—Pollen-cells (microspores) of Gymnosperms. *A*, of a Cycad; *y*, rudimentary first stage (prothallium), one pollen-cell germinating. *B*, pollen-cells of a Pine, side and top views, showing bladder-like enlargements of outer cell-wall, *bl*; the rudimentary prothallium is shown here also. Much magnified.

454. The pollen-cells are roundish, and covered by a double wall, the outer being thick and hard, and in some

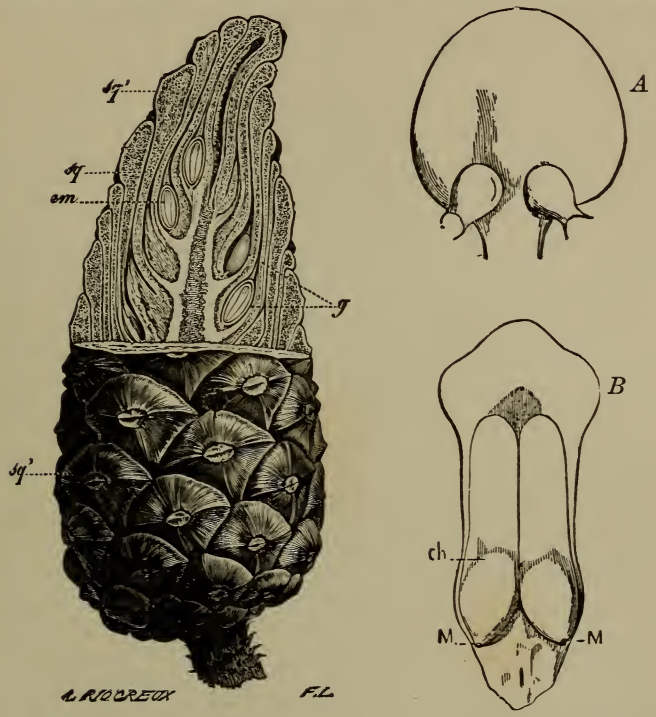


FIG. 143.—A ripe cone of a Pine, partly cut away to show the position of the seeds, *g*; *A*, a scale from a young cone, upper side showing two ovules (enlarged); *B*, the same when mature, showing two winged seeds, *ch*. Each seed-coat has a small pore, *M*, through which the first root will grow in germination.

cases swollen out into bladder-like enlargements, apparently for the purpose of enabling the cell to be carried in the air (Fig. 142, *B*). One or more cells of the rudimentary sexual plant are always present (Fig. 142, *y*).

455. The ovule-bearing flowers consist of the well-known cones which, when mature, bear the seeds (Fig. 143). The cone consists of a stem bearing many leaf-like scales closely crowded together, and upon these the ovules are

produced. Each ovule has one coat which grows up from below, almost covering it; but as the ovules grow they bend down, so that the opening through the coat comes to be below (Fig. 143, *A* and *B*).

456. In the axis of the ovule near its apex a cell becomes differentiated from the rest as the archespore ; this grows larger, divides several times, and one of the deeper-lying daughter-cells growing rapidly becomes a macrospore (embryo-sac). The macrospore now forms many nuclei, which eventually become as many cells, filling it up with a solid tissue (the sexual plant, or prothallium), and in this are developed one, two, or more rudimentary archegones, each with its germ-cell. Thus we see that the development which takes place here inside of the ovule (which corresponds to the spore-case) is similar to that which in the Lycopods takes place only after the macrospore has separated itself from the parent-plant.

457. Fertilization takes place as follows: The scales of the cone open slightly, permitting the pollen, which has been carried in the wind, to roll down to their bases where the ovules are. Here the pollen-cells germinate, and their tubes enter the opening in the ovule-coat and push through the tissues to the archegones, where the pollen-protoplasm is fused with that of the germ-cell (Fig. 144).

458. As a result of the fertilization there is first a growth of a row of cells (called the suspensor, erroneously), upon the end of which the embryo begins to form. The root-end of the embryo is always in contact with the suspensor, so that, taking the whole embryo at maturity, the supensor is at one end and the little leaves at the other. Moreover, the root-end of the embryo is always directed toward the opening in the ovule- or seed-coats. The em-

bryo proper is composed of a little stem ending in a short root below and bearing a number of little leaves (cotyledons) above. The stem ends in a bud, above and within

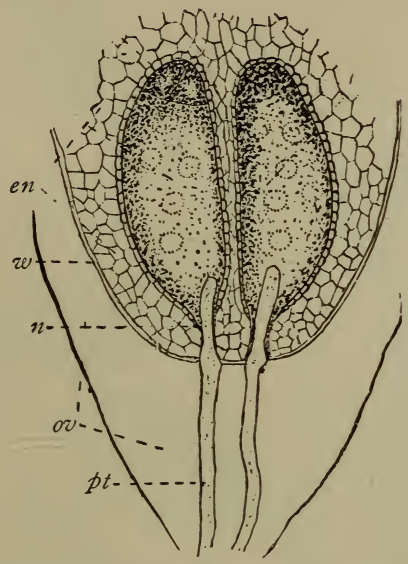


FIG. 144.—Part of a Pine-ovule. *ov*, the body of the ovule; *w*, embryo-sac filled with endosperm, *en*, which contains two large cells (rudimentary archegones); *n*, neck of archegone; *pt*, pollen tubes growing upward into necks of archegones. Magnified 30 times.

the whorl of leaves. During the growth of the embryo the ovule enlarges, and its coat becomes thicker and harder, and at last, when growth within has ceased, it separates from the parent-plant as a seed (Fig. 145, *I*).

459. In germinating the seed first absorbs water and swells so as to burst its thick coat; the root elongates and pushes out into the soil (Fig. 145, *A*), soon sending out little branches. The leaves (cotyledons) are in contact with the endosperm, which is rich in starchy and sugary matters, affording the plantlet food for its growth.

Finally, by the elongation of the leaves, the whole plant is pushed out of the now empty seed-coat (Fig. 145, *III*).

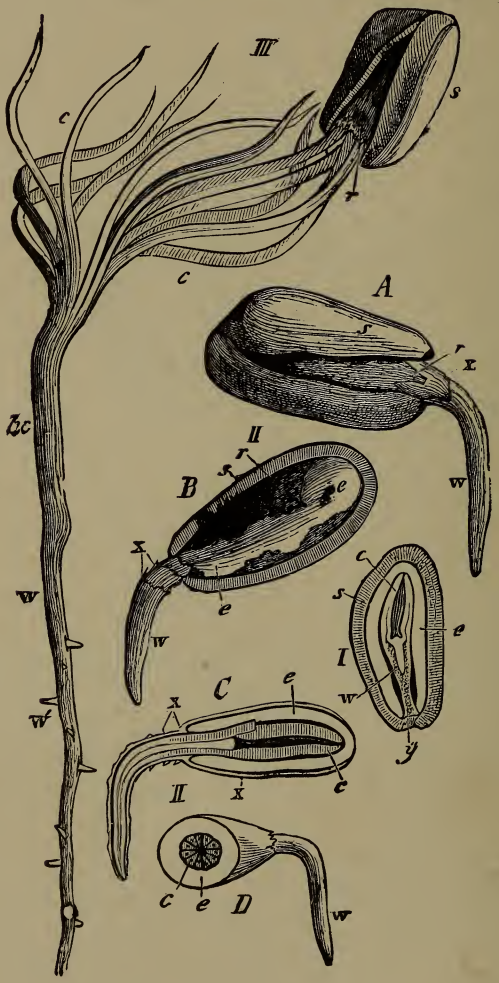


FIG. 145.—Seeds of a Pine in different stages of germination. *I*, ripe seed in longitudinal section; *s*, seed-coat; *e*, endosperm; *w*, axis of embryo; *c*, leaves; *y*, opening in seed-coat. *II*, *II*, four views of the beginning of germination: *A*, external view; *B*, with half of the seed-coat removed; *C*, in longitudinal section; *D*, in transverse section; *s*, seed-coat; *e*, endosperm; *c*, leaves; *w*, root. *III*, germination completed.

460. The tissues of the Gymnosperms are individually but little higher than those of the Fernworts, but in their

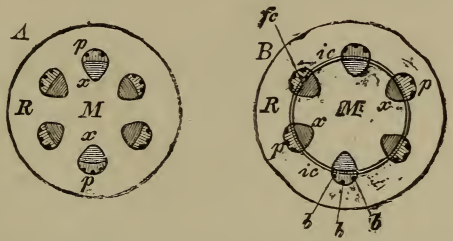


FIG. 146.—Diagrammatic cross-sections of stems, showing the fibro-vascular bundles, *fc*, of which *x* is the woody side and *p* the softer or bark side; *b*, *b*, *b*, bast-fibres; *R*, *M*, the fundamental tissues of the stem, of which *R* (the rind) is the cortical and *M*, the medullary portion, or pith; *ic*, a belt of cambium which extends from bundle to bundle.

arrangement they show great and important differences. The fibro-vascular bundles are of the collateral form, and are so placed in the stem that the harder and more woody side is nearer the centre of the stem, while the softer side is always nearer to the surface (Fig. 146, *A*). The inner part of the bundles is composed mostly of long, large cells, the tracheïds, which have the well-known characteristic bordered pits (Fig. 147). The outer part contains, besides other tissues, a little fibrous tissue (bast-fibres). Between these two halves of the bundles there is a thin layer of growing cells (cambium) which is continuous with a layer between the bundles (Fig. 146, *A* and *B*). At this stage the stem is composed

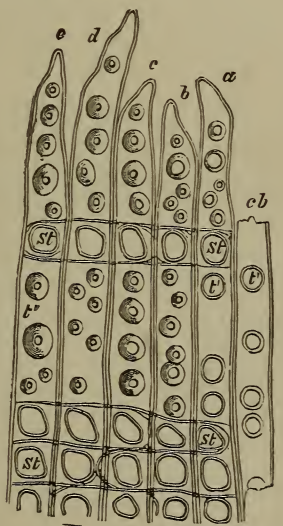


FIG. 147. — Longitudinal section of wood of a Pine (Pinus sylvestris). Bordered pits, *t'*,*t'*,*t''*; *a*–*e*, parts of six tracheïds; *st*, large pits, where medullary rays touch tracheids. Magnified 325 times.

of an inner mass of cells, the pith (*M*), and an outer, the rind, or cortex (*R*), connected with one another by the broad rays between the bundles (Fig. 146).

461. As the stem grows older the cambium of the bundles keeps on forming tissues similar to those already found in the bundle; in other words, the woody part of each bundle is increased on its *outer* side, and the bark part on its *inner* side. In the mean time the cambium between the bundles gives rise to new bundles, which then increase in size in the manner described above. The woody part of the stem soon comes to have the shape of a cylinder, surrounded by a softer bark portion as a sort of sheath.

462. The stem grows in thickness in the warm part of the year, but stops its growth as cold weather comes on. The first growth in each year is most vigorous, the cells being larger, while those formed toward the end of the season are regularly smaller and smaller until activity ceases. This manner of growth produces the well-known growth-rings, so readily seen in a cross-section of any pine or spruce stem. As there is generally but one period of growth each year in the cooler climates, every growth-ring represents a year of the tree's life; but it appears that occasionally there may be two periods of growth in a year, and consequently two growth-rings.

463. Many members of this class have canals running through the tissues of their stems and leaves, in which a resinous turpentine is found.

Practical Studies.—(*a*) In the spring of the year collect a quantity of the staminate cones of a pine (Scotch or Austrian are very good), and preserve such as are not wanted for immediate use in alcohol. Collect at the same time the young ovule-bearing cones which are to be found upon the ends of the new shoots as ovoid bodies, 8 to 10 mm. long by 5 to 6 broad.

(*b*) Split a staminate and an ovule-bearing cone vertically, and study their structure, comparing the one with the other. Dissect out a stamen and an ovule-bearing scale, and compare. In the former note the pollen-sacs, and in the latter the ovules (Figs. 141 and 143).

(*c*) Study pollen-cells from young and mature staminate cones. In the young pollen look for the cells representing the sexual plant (prothallium); in the ripe pollen note the bladder-like enlargements of the outer coat (Fig. 142, *B*).

(*d*) Note that the ovule-bearing cones of Scotch and Austrian pines are two years in coming to maturity. Make vertical sections of cones of various ages, and note the growth of the seed. Note the thin wing (useful in their dispersion) on the seeds. Make longitudinal sections of seeds, and note the little plantlet with its several leaves (cotyledons).

(*e*) Make cross-sections of leaves, and note the turpentine-canals, one near each angle, with others symmetrically arranged between. Make cross-sections of the young twigs, and note the canals in the rind or bark. Make similar sections of the wood of the trunk, and note similar canals at intervals.

(*f*) Make very thin cross-sections of the mature wood of the stem, and note shape and size of the cells; note also the gradual decrease in the size in passing from the inner to the outer side of a growth ring. Now make a very thin longitudinal-radial section, and observe the bordered pits (Fig. 147). A longitudinal section at right angles to the last (longitudinal-tangential) will show no bordered pits. In all these sections note that the wood is made up of but one kind of cells, viz., tracheïds.

(*g*) In a cross-section of a stem note the thin radiating plates of tissue (medullary rays), in many cases extending from pith to bark. In longitudinal-tangential section of the stem these rays are seen in cross-section to be made of thick-walled cells (stony tissue). In longitudinal-radial sections the rays are seen split lengthwise (Fig. 146, *st*).

(*h*) Make very thin cross-sections of the stem through bark and wood, and note the layers of very soft thin-walled tissue (cambium) between wood and bark. This may be made more evident by soaking the section for a few hours in carmine, by which the cambium will be stained.

There are three orders of Gymnosperms (including about 420 species), viz.:

464. The Cycads (Order 36, CYCADEÆ) are large or small trees, with much the general appearance of the palms

and tree-ferns. They are of slow growth and are long-lived; the stem elongates by a slowly unfolding terminal bud, which gives rise to a crown of widely spreading pinnate leaves, which are constantly renewed above as they die and fall away below. About eighty-three species are now known, all confined to tropical or sub-tropical climates. In geological times (Triassic and Jurassic) they were very abundant.

465. The Conifers (Order 37, CONIFERÆ) are mostly trees of a considerable size, with branching, spreading, or spiry tops, as the pines, spruces, firs, etc., etc. They are generally of rapid growth, and in many cases attain a great height and diameter. In the greater number of species the leaves are persistent, and the trees, consequently, evergreen.

466. The order contains two families, viz., Taxaceæ and Pinaceæ, including about three hundred species, which are distributed mainly in the cooler climates of the globe. Ninety or more species occur in North America, and constitute in many places enormous forests hundreds of miles in extent.

The pines (Pinus) include the most important trees of the order. The White pine (P. strobus), formerly very abundant from the Great Lakes eastward, furnishes the greater part of the "pine lumber" so largely used in the Northern States for building and other purposes. The Sugar-pine (P. lambertiana) of California resembles the White pine, but is much larger, being often 60 to 90 metres (200 to 300 feet) in height, with a trunk 3 to 6 metres (10 to 20 feet) in diameter. The Southern pine (P. palustris), abundant from the Carolinas to Texas, is a tree of moderate dimensions, whose hard wood is "superior to that of any other North American pine," and is known in the markets as Yellow or Georgia pine. Scotch pine (P. sylvestris) and Austrian pine (P. laricio), both natives of Europe, are extensively planted in this country. Besides the spruces, firs, larches, cedars, and many other well-known trees, the order contains the two species of great Redwoods. The most remarkable is called the Big Tree

(Sequoia gigantea), and grows in a few valleys on the western slope of the Sierra Nevada of central California. It attains a height of more than 100 metres (300 feet) and a diameter of 6 to 10 metres (20 to 30 feet). The other species is the common Redwood (S. sempervirens), confined to the Coast-Range mountains of California. It is but little inferior to the preceding in size, and its wood is extensively used for building and other purposes.

In the southern hemisphere the Kauri pine (Agathis australis) of New Zealand, the Norfolk Island pine (Araucaria excelsa) of the South Pacific Ocean, and others represent a group of conifers closely related to those which were abundant in ancient geological times.

467. The Joint-firs (Order 38, GNETACEÆ) include a few undershrubs or small trees (about 36) mostly natives of the warmer parts of the world. Their curious structure is far too difficult to be taken up here.

Systematic Literature.—Gray, Manual of Botany, 489–4 (6th edition). Coulter, Manual of the Botany of the Rocky Mountain Region, 428–433. Brewer, Watson, and Gray, Botany of California, **2** : 108–128. De Candolle, Prodromus, **16**^{2} : 345–547.

CLASS 15. ANGIOSPERMÆ. THE ANGIOSPERMS.

468. The plants of this class have, in most cases, more or less elongated stems; these are solid at first, and in the great majority of cases they remain so. They usually bear ample leaves, with parallel or netted veins.

469. Their reproductive organs are mostly collected into definite and distinct flowers, which often show great beauty of form and color. The pollen-bearing leaves (stamens) resemble those of the Gymnosperms, but the ovule-bearing leaves (carpophylls) are folded into a closed vessel (ovary).

470. Most Angiosperms are terrestrial and chlorophyll-bearing plants; there are, however, many aquatic and aerial species and a considerable number of parasites. They range, also, in size and duration, from minute annuals,

a millimetre in extent, to enormous trees, 50 to 150 metres high and many centuries old.

471. We have seen (pp. 240–1) that in the Gymnosperms the flower consists of a stem upon which are the leaves which bear reproductive cells. The flower of the Angiosperms is likewise a stem, bearing leaves which have to do with reproduction. In this class, however, there is, as a rule, a division of labor, as we may say: instead of all the leaves bearing reproductive cells, some of them are modified in form, color, or structure, so as to make the flower more conspicuous, which is, as we shall see, to the advantage of the plant.

472. There are so many particular forms of flowers that it would be impossible to notice or describe them all in this place. In some cases the flower is a little stem (axis) upon which are pollen-bearing or ovule-bearing leaves (stamens or ovaries); these clusters of reproductive organs may have a number of sterile leaves below them on the stem, the floral leaves, or perianth. In other cases both kinds of reproductive organs are in one flower, when the ovaries are highest on the stem, the stamens being next, and the sterile leaves (if any) lowest of all (Fig. 148). There is, moreover, great diversity in the development of the sterile leaves, varying from a few small green or pale leaves to two or more distinct whorls of sepals (the outer) and petals (the inner) which may show great differences in shape, size, texture, and color.

473. The stamens of Angiosperms often bear so little resemblance to leaves that their real nature would not be suspected. There is usually a slender stalk, the filament, at the top of which are from one to four pollen-sacs, the latter forming the anther. We may regard the filament

and its extension (the so-called connective) between the pollen-sacs as representing a very narrow leaf upon which the pollen-sacs develop as outgrowths. Sometimes the stamen is broad, showing at once its leafy nature.

474. The development of the pollen-cells is like that of the spores of Fernworts and the pollen of Gymnosperms. Certain internal cells (called pollen mother-cells) in the

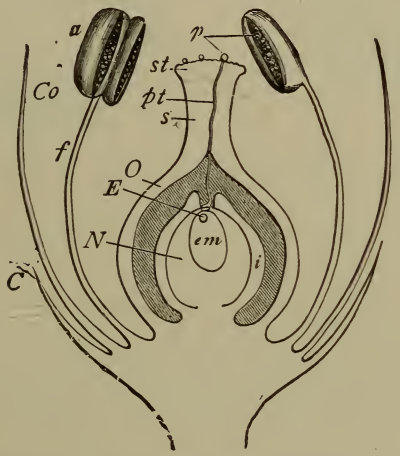


FIG. 148.—Diagrammatic section of a flower. *C*, calyx; *Co*, corolla; *f*, the filament, and *a*, the anther, of the stamen; *p*, pollen-cells, some in the anther, others on the stigma; *O*, the ovary, surmounted by the style, *s*, and the stigma, *st* (this ovary contains one ovule, which has a single coat, *i*, enclosing the ovule-body,) *N*; *em*, the embryo-sac; *E*, germ-cell; *pt*, a pollen-tube penetrating the style, and reaching the germ-cell through the micropyle of the ovule.

young pollen-sacs undergo division into four parts, which become rounded and covered with a double coat or wall. The outer coat is often much thickened, and may be roughened by ridges or prickles (Fig. 149). There are two nuclei in each pollen-cell: (1) the vegetative nucleus, which is the remnant of the prothallium, and (2) the generative nucleus, which is the homologue of an antherozoid.

475. The pollen-cells germinate in moisture by sending out a tube which is a prolongation of the inner coat. The protoplasm of the cell passes freely down the tube to its extremity, and carries with it both the vegetation and generation nuclei.

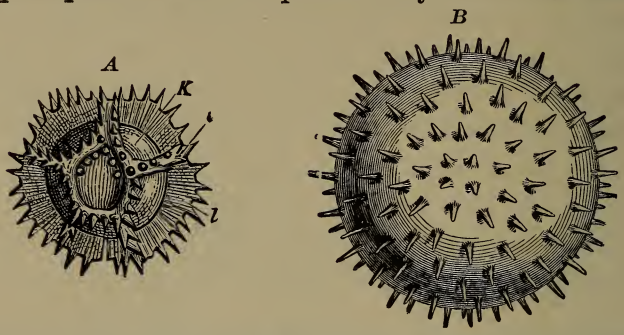


FIG. 149.—Pollen-cells with roughened walls. *A*, of Chicory; *B*, of Flowering Mallow (Lavatera). Highly magnified.

476. The ovule-bearing leaves of Angiosperms bear still less resemblance to ordinary leaves than do the stamens. In the simpler cases the young leaf becomes curved so that its edges touch and finally grow together, forming the ovary, which usually tapers above into a style or stalk supporting a glandular structure, the stigma (Fig. 148, *n*). The whole ovule-bearing organ, composed of ovary, style, and stigma, is usually known as the pistil. In many plants several pistils grow together, and thus form a compound pistil.

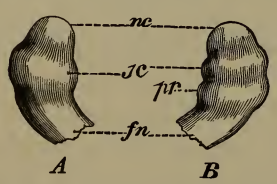


FIG. 150.—Very young ovules. *nc*, ovule-body; *sc*, inner, and *pr*, outer, coats just beginning to grow; *fn*, ovule-stalk. Magnified 140 times.

477. The ovules grow upon the inner (i. e., upper) surface of the leaf which forms the ovary, or at its base (Fig. 148), or more frequently upon its margins. At first it is a simple rounded outgrowth of a few cells; as it grows older a cir-

cular ridge arises upon it, which often is soon followed by another (Fig. 150, *A* and *B*). These ridges grow out and upwards so rapidly that they overtake and enclose the ovule-body, leaving but a small opening or pore. The body of the ovule, called the *nucellus*, is relatively large in the lower Angiosperms, while it is small in the higher orders.

478. In the nucellus an axial cell develops into the archespore, which soon undergoes transverse division into four

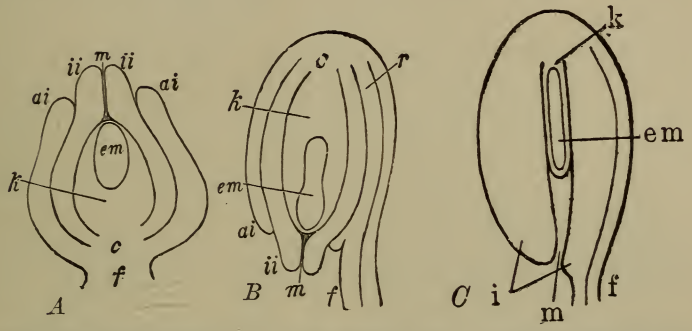


FIG. 151.—Diagrammatic longitudinal sections of ovules. *k*, the nucellus or body of the ovule with its embryo-sac, *em*; *ai*, the outer, and *ii*, the inner, coat; *m*, the opening in ovule-coat (micropyle); *c*, the base of the ovule; *f*, the ovule-stalk; *A*, a straight ovule; *B*, an inverted ovule; the long stalk, *f*, has fused with the outer coat of one side of the ovule. *C*, an inverted ovule with but one coat, and a slender nucellus.

cells (rudimentary macrospores); one of these (usually the lowermost) grows at the expense of the remainder, crowding and eventually destroying them. There is thus but one mature macrospore in each nucellus (macrosporangium). In the further development (germination) of the macrospore its nucleus divides, and the two daughter-nuclei move to opposite ends of the macrospore-cavity; there they divide again and again, producing two terminal tetrads; now one nucleus from each tetrad moves to the centre of the macrospore-cavity, where they fuse into one, thus constituting the nucleus of the embryo-sac. One of the nuclei at the apex becomes the germ-cell (oösphere or egg-

cell), the other two, the synergids, are sterile. The nuclei at the base constitute a rudimentary sexual plant (prothallium) which does not develop until much later. Since the tissues of the ovule-body can sufficiently nourish the germ-cell, there is no need of a prothallium at this time, and there is also an almost complete suppression of the archegone-walls.

479. Fertilization takes place as follows: The pollen-cell, resting upon the moist surface of the stigma, germinates, and its tube penetrates the soft tissues of the stigma and style, finally reaching the cavity of the ovary, where it enters the ovule through the opening in the coats (Fig. 152, *A*). Here it comes in contact with the apex of the

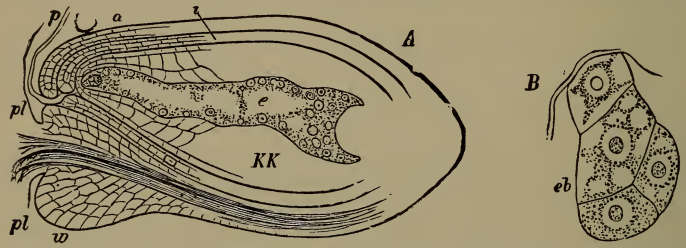


FIG. 152.—*A*, a longitudinal section of an ovule of the Pansy, after fertilization; *a* and *i*, coats of the ovule; *p*, pollen-tube; *e*, embryo-sac, with the very young embryo at one end and free endosperm-cells at the other. *B*, apex of embryo-sac, *e*; *eb*, very young embryo of four cells.

ovule-body, and soon reaches the embryo-sac. The generative nucleus of the pollen-tube unites with the germ-cell, which then forms a wall about itself; it then divides transversely one or more times, forming a row of cells (the suspensor), at the end of which an embryo soon begins to form by the fission of cells in three planes (Figs. 152, *B*, and 153, *I* to *IV*).

480. At first the embryo is a minute rounded cell-mass attached to the end of the row of cells, and in some plants it passes but little beyond this stage until after the ripen-

ing of the seed. In most cases, however, the cell-mass continues its growth until it has formed a little stem, bearing rudimentary leaves above and a root below. There are to be found all degrees of simplicity in the embryos of An-

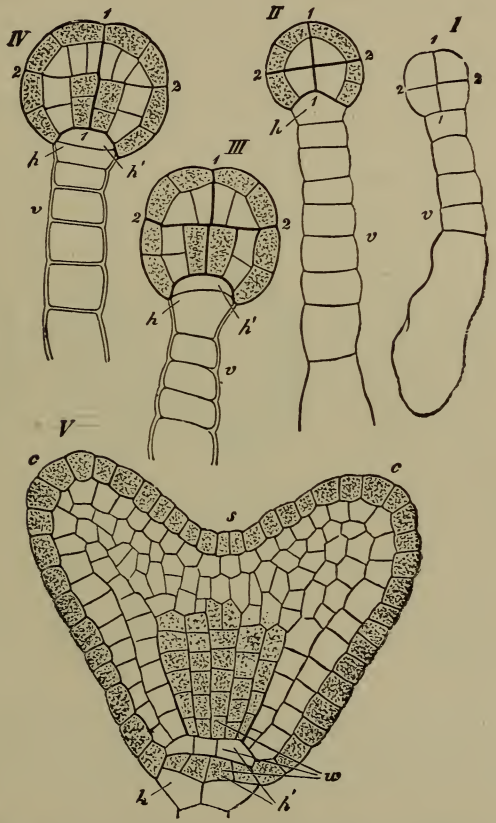


FIG. 153.—Embryo of Shepherd's-purse (Bursa), in various stages. *v*, the suspensor. In *V* the root-cells, *w*, first appear, the rudimentary leaves, *c*, *c*, and stem, *s*, already formed. Highly magnified.

giosperms, from the rounded cell-mass (thallus) to the well-formed plantlet provided with distinct root, stem, and leaves.

481. While these changes are going on, the nuclei of the embryo-sac increase rapidly (by mitotic division) and form cells which fill up a considerable part of its cavity. These cells constitute the endosperm, and serve somewhat later to nourish the growing embryo. This nourishing tissue is the homologue of the sexual plant (prothallium) of the Fern-worts, here greatly belated.

482. The embryo in its growth gradually absorbs the endosperm. In many cases growth is checked in the ripening of the seed, before much of the endosperm is used up (Fig. 154, *A* to *D*); in such seeds the embryo is small and

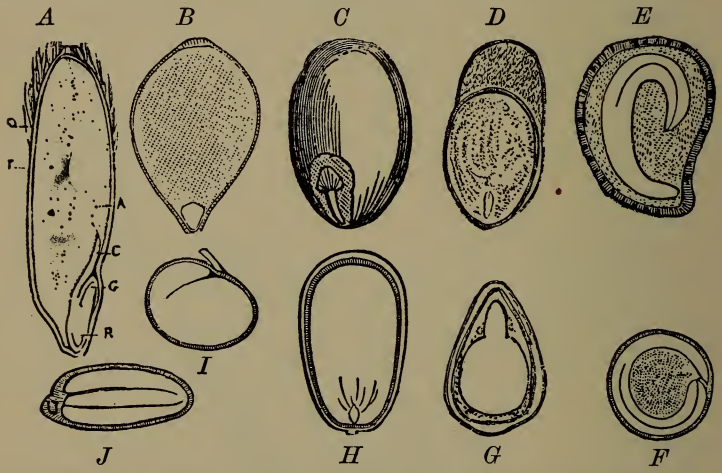


FIG. 154.—Magnified sections of seeds, showing embryos and endosperms. *A*, Oat; *B*, Sedge; *C*, Coffee; D, Marsh-marigold; *E*, Bittersweet; *F*, Goosefoot; *G*, Nettle; *H*, Oak; *I*, Sweet Pea; *J*, a Mustard. In *A* to *D*, small or minute embryo in large endosperm; *E* to *G*, larger embryo and smaller endosperm; *H* to *J*, large embryo and no endosperm.

poorly developed. In other cases more (Fig. 154, *E* to *G*), or in still others all (Fig. 154, *H* to *J*), of the endosperm is absorbed; in these the embryos are much larger and better developed. Where endosperm remains in a seed, its cells are generally filled with starch, or less frequently with oily matters; where no endosperm remains, there is always

a storage of starch or oily matter in some part of the embryo. While the embryo is growing inside of the ovule, the outer ovule-coat generally becomes thicker and harder, all the ovule-tissues become drier, and at last the hard, dry ovule, now called a seed, separates at its base and falls to the ground.

483. The seed in germinating absorbs moisture, swells up, and generally bursts its coat. The embryo resumes its growth, sending out its root into the soil, and its stem and leaves upward into the air. Where there is endosperm, the embryo grows by absorbing food from it; where there is no endosperm, the large embryo is strong enough to grow for a time by using the store of food contained within itself. In some cases (e.g., beans, squash, melon, etc.) all the leaves withdraw from the seed-coat and appear above ground, while in others the first one or two leaves (cotyledons) remain in the seed in the ground, only the succeeding leaves coming up into the light and air, as in peas, wheat, etc.

484. We have seen that fertilization of the germ-cell not only caused the latter to develop into a plantlet, but excited the tissues of the ovule to a growth which they would not have made otherwise. This excitation of growth extends much further than the ovule ; it commonly causes the ovary to undergo considerable changes, and in some cases even parts of the perianth or the stem which bears the organs of the flower. These changes give rise to the *fruit* of Angiosperms.

485. The changes which most frequently take place in the growth of the fruit are such as (1) an increase in the number of ovule-chambers by the formation of false partitions, or (2) a decrease in their number by the oblitera-

tion of some; (3) the growth of wings or prickles upon the exterior of the fruit; (4) the thickening and formation of a soft and juicy pulp; (5) the hardening of some portions of the wall by the development of stony tissue; (6) the thickening and growth of the calyx or receptacle.

486. In cases where the walls remain thin and eventually become dry the fruits are said to be *dry*—e.g., in the bean; where the walls become thickened and more or less pulpy, they are *fleshy*—e.g., the peach.

487. It is unnecessary here to describe the various kinds of fruits. It is enough to point out that they all appear to have to do with the protection or dispersion of the seeds they contain. Thus the hard walls (as of nuts, achenes, etc.) or the bitter pulp of some (as of certain berries) are protective, while the sweet pulp (many berries, drupes, etc.) and explosive capsules of others serve to distribute the seeds.

488. The particular structure of the flower, its position on the plant, and its relation to other flowers in forming flower-clusters of this or that shape, all have reference to pollination (i.e., the placing of the proper pollen upon the stigma). The pollen-cells are dependent for transportation to the stigma upon (1) the wind (*anemophilous* flowers); (2) certain contrivances by means of which insects (or rarely birds) are made to carry the pollen from anther to stigma (*entomophilous* flowers); (3) the favorable position of the anthers and stigmas, bringing the pollen in the opening anther into contact with the stigmatic surface (*autogamous* flowers).

489. The grasses and sedges, and the oaks, beeches, chestnuts, walnuts, birches, and their allies, and a few others, have wind-pollinated flowers. In these the pollen

is produced in great abundance, and the flowers are mostly small, regular in form, simple in structure, uncolored, and destitute of nectar (honey). The pollen-bearing flowers are always in clusters which are exposed to the wind, as in grasses at the top of the plant.

490. A great many plants have insect-pollinated flowers; these are, as a rule, large, colored, sweet-scented, and provided with nectar-glands; the nectar acts as a bait, and the showiness and scent as guides, to honey-loving insects, which, by various contrivances in the flowers, are made to come in contact with the anthers of one flower and the stigmas of another, in the first dusting their bodies with pollen, which in the second adheres to the stigmas.

491. Large flowers are frequently solitary, but smaller ones are, as a rule, massed in clusters which thus become conspicuous. In the golden-rods we have a good illustration of an extreme case of this kind, the individual flowers being very small and inconspicuous, while the flower-clusters of hundreds of massed flowers may be seen for a long distance. In sunflowers, in addition, the marginal flowers in the cluster develop an especially showy perianth, surrounding the whole with conspicuous rays.

492. Many showy flowers have no nectar (honey) glands, but in general some part of the flower secretes a sweet, sugary fluid which is attractive to insects and some birds. The nectar is always situated in the back part of the flower, so that in securing it the insect is obliged to come near to the pollen-sacs or stigma.

493. In this connection the various irregularities of size and form in the parts of the perianth, as well as of stamens and pistils, have a meaning. Thus the perianth-leaves may grow together into a tube, in which case the nectar is

at its bottom; or they may be of different sizes, as in orchids, beans, peas, etc., where they are so placed as to admit of access to the nectar from one direction only. In some tubular flowers there are two forms in the same species, those of some plants having long stamens and short styles, while in others the structure is exactly the reverse. Insects in getting honey from these will pollinate the long-styled flowers with pollen from the long stamens of other flowers, and *vice versa*. There is also very often a greater or less difference in the time of maturity of the stamens and pistils. In some the pollen is set free before the stigma is ready for pollination; in others it is the reverse. This (and the preceding) arrangement prevents pollination of a pistil by pollen from the stamens of the same flower; i.e., close fertilization is prevented.

494. Self-pollinated (autogamous) flowers are much less numerous than those which are wind- or insect-pollinated, and it is doubtful whether there are any species of plants all of whose flowers exhibit constant self-pollination (autogamy). There are a good many plants, however, which have two forms of flowers, viz., large, showy, nectar-bearing, insect-pollinated ones, and small, inconspicuous, self-pollinated ones, generally with a rudimentary perianth. Flowers exhibiting this form of autogamy are said to be *cleistogamous*.

495. Examples are to be met with in some violets, wild touch-me-nots, etc.; early in the season these have large flowers, which are pollinated by insects, but later only small cleistogamous ones appear, and in some violets these are subterranean. Without doubt it frequently happens that the pollen of wind- and insect-pollinated flowers falls upon their stigmas, resulting in accidental self-pollination;

but too frequent a recurrence of this is guarded against by various structural devices.

496. The foregoing are but a few of the general modifications which flowers have for securing proper pollination; they must serve to direct the student's attention to this interesting part of the study of plants, which can be taken up in connection with the writings of Darwin, Müller, Gray, and others.

Practical Studies.—(*a*) Collect a few wild buttercup flowers. Begin at the lower side of the flower and carefully remove the five green sepals constituting the so-called calyx, next the five yellow petals constituting the so-called corolla, next the many stamens, and last the numerous small pistils which cover the rounded end of the floral stem. Make a careful drawing of a representative of each part.

(*b*) Mount in water (after moistening with alcohol) a little of the pollen of the morning-glory, sunflower, mallow, and Indian corn. Note the surface markings. Crush the cells and test with iodine. Pollen-grains may be germinated by placing them in a five-per-cent solution of common sugar in water. The pollen-tubes may also be found by carefully mounting stigmas or longitudinal sections of stigmas. Many grasses are good subjects for such studies.

(*c*) Remove the pistil from a fresh pea-flower. Split it longitudinally, and observe that the ovules are in a row along one seam (suture). Make many cross-sections of another pistil, so as to secure sections of ovules, in which note the ovule-body and the coats. Make cross-sections of younger and younger unopened flowers of the pea, and study the development of the ovary and ovules. It is very easy to get specimens showing the ovary not yet closed, and the ovules as very small outgrowths from its margins.

(*d*) Make longitudinal sections of several young pea-pods in such manner as to secure thin sections of the ovules. By selecting pods of different ages, the large embryo sac, with the young embryo in various stages of growth, may be observed.

(*e*) Carefully dissect and examine a pea after soaking over night in water. Note the short curved stem, tipped by a root, the two thick, starch-gorged leaves (cotyledons) with smaller leaves between them. Examine in like manner a bean, seeds of the apple, squash, buckwheat, oat, Indian corn. Note the endosperm when present.

(*f*) Examine in succession ripened fruits as follows: 1, marsh-

marigold (follicle); 2, pea (legume); 3, mustard (capsule); 4, parsnip (cremocarp); 5, oak (nut); 6, sunflower (achene); 7, Indian corn (caryopsis); 8, melon or cucumber (pepo); 9, gooseberry (berry); 10, cherry (drupe); 11, apple (pome). Numbers 6 and 7, which are popularly called seeds, are composed of a large seed enclosed in a tightly fitting ovary-wall.

(*g*) Study the Indian corn as an example of a wind-pollinated (anemophilous) plant. Note the position of staminate (in the tassel) and pistillate (in the ear) flowers. Estimate the relative number of pollen-cells, and ovules (one in each ovary).

(*h*) Study the position of the nectar in clover (at the bottom of the corolla), columbine (in deep sacs of the petals), and buttercup (on glands at the base of the petals).

(*i*) Examine flowers from several different plants of eyebrights (Houstonia), puccoon (Lithospermum), and cultivated primrose. Observe that on some plants the flowers have long stamens and short styles, while in others they are the reverse. By measurements the anthers of the one form will be found to have exactly the height of the stigmas of the other. Many other flowers show this dimorphism; a few show trimorphism, i.e., three forms.

(*j*) Observe the flowering of spring-beauty (Claytonia), and notice that the stamens mature before the stigmas are ready for pollination. Observe in like manner thistles and sunflowers in which also proterandry, as it is called, takes place. Now observe the flowering of the strawberry and the apple, in which the pistils mature before the stamens. This is known as proterogyny. Both proterandry and proterogyny are included under the general term of dichogamy.

(*k*) Observe the large early flowers of violets, which are dependent upon insects for pollination. Notice that after a while none of these appear, but only small ones destitute of petals. In the common yellow violet these are borne on the stem above the ground, but in blue violets they are often underground. These small flowers are self-pollinated (cleistogamous).

497. The fibro-vascular bundles of the stems of Angiosperms are entirely of DeBary's "collateral" class; that is, each bundle in cross-section is more or less distinctly two-sided, viz., wood and bark. Each of these sides generally contains soft, fibrous, and vascular tissues.

498. The disposition of the bundles in the Angiosperms is for the most part dependent upon the position of the

leaves. Nearly all the first-formed bundles are of the kind termed "common bundles"; that is, they extend on the one hand into the leaf, and on the other down into the stem.

499. The general arrangement may be illustrated by Fig. 155 in which there pass down from each leaf three bundles; at the lower internode these are, on the left, *a*, *b*, *c*, and, on the right, *d*, *e*, *f*. At the next internode, where the leaves stand at right angles to the lower ones, there are three bundles again, *g*, *h*, *i*, and *k*, *l*, *m*; these are largest at their points of curvature, and they dwindle in size as they pass downward and finally unite with the bundles from the lower pair of leaves. The bundles from the third internode pass downward, and in like manner join those from the second pair of leaves, and so on. The bundles from the third internode pass downward, and in like manner join those from the second pair of leaves, and so on. Thus in such a stem every bundle passes downward through one internode before joining another, and in any internode all the bundles are derived from the leaves at its summit.

500. In some Angiosperms the bundles in a cross-section of a stem are separate from one another, while in others they soon become connected by a cambium-ring as in the Gymnosperms. In the perennial species this gives rise to a marked difference in the structure of the stem (Fig. 156, *A* and *B*).

501. The tissues of Angiosperms are the most varied and highly developed of any in the vegetable kingdom. Not only is every tissue abundantly represented, but each one shows almost numberless more or less well-marked varieties. Moreover, the structures which they form, as

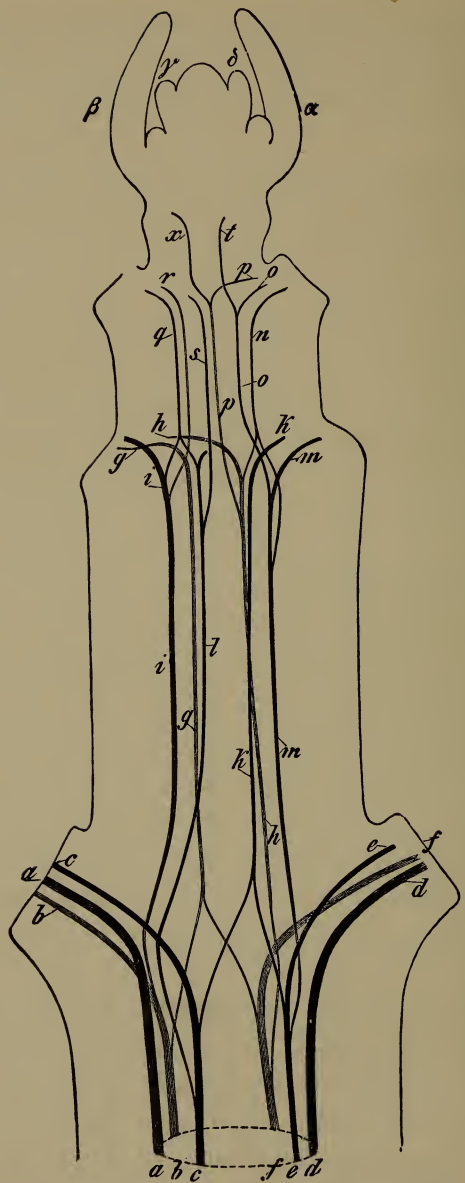


FIG. 155.—The fibro-vascular system of the stem of a Virgin's-bower (Clematsi).

the solid (woody) parts of the stems, are of a higher order and far more complex than those in any other groups of plants.

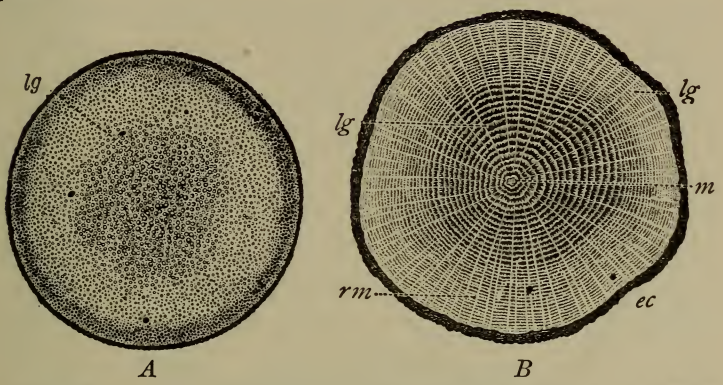


FIG. 156.—Cross-sections of tree-trunks. A, of a Palm; B, of an Oak, *lg*, woody, and *ec*, cortical (bark), portion; *m*, pith; *rm*, medullary rays.

Practical Studies.—(*a*) Make cross-sections of young stems of the asparagus and hickory. Note the difference in arrangement of the bundles. In like manner compare cross-sections of young stems of virgin's-bower (Clematis) and green-brier (Smilax).

(*b*) Make vertical sections of the foregoing, and note the relation of the bundles to the leaves.

(*c*) Make cross and longitudinal sections of the solid (woody) part of a bamboo or green-brier stem, and compare with similar sections of oak or hickory. In the latter note the pith, medullary rays, and distinct bark, not present in the former.

(*d*) In the sections of oak and hickory note the cambium-zone which lies between the inner solid (woody) mass, and the outer softer portion.

502. The Angiosperms include about 100,000 species and are readily separated into two sub-classes, as follows:

Sub-Class I. **Monocotyledoneæ** (the Monocotyledons).—The first leaves produced by the embryo are alternate; the endosperm is usually large and the embryo small.

Sub-Class II. **Dicotyledoneæ** (the Dicotyledons).—The first leaves of the embryo (cotyledons) are opposite; the

endosperm is very often rudimentary or entirely wanting, and the embryo is generally large.

SUB-CLASS I. **THE MONOCOTYLEDONS.** *Monocotyledoneæ.*

503. The first leaves of the embryo are alternate ; hence we say that they have one cotyledon. The venation of the leaves is for the most part such that the veins run more or less parallel to one another, and when they join each other enclose four-sided spaces; rarely, however, their veins are irregularly distributed and form an irregular network.

504. The germination of Monocotyledons may be illustrated by the Indian corn. Here the embryo lies partly

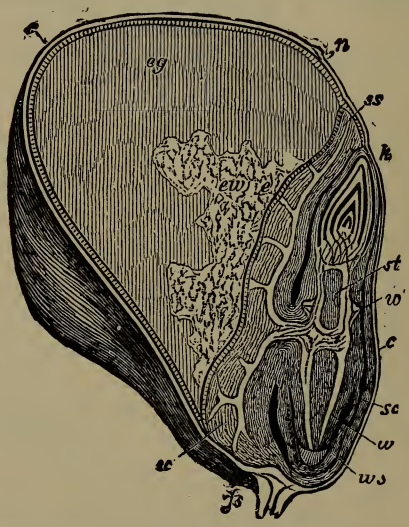


FIG. 157.—Longitudinal section of the seed of Indian Corn. *c*, adherent wall of the ovary; *n*, remains of the style ; *fs*, base of the ovary (all the remainder of the figure is the true seed); *eg*, *ew*, endosperm ; *sc*, *ss*, cotyledon ; *e*, its epidermis; *k*, young leaves ; *w*, the main root; *w'*, roots springing from the stem. Magnified 6 times.

imbedded in one side of the large endosperm (Fig. 157.) The first leaf of the young plant (the cotyledon, or scutellum), *sc*, has its broad dorsal surface in contact with the

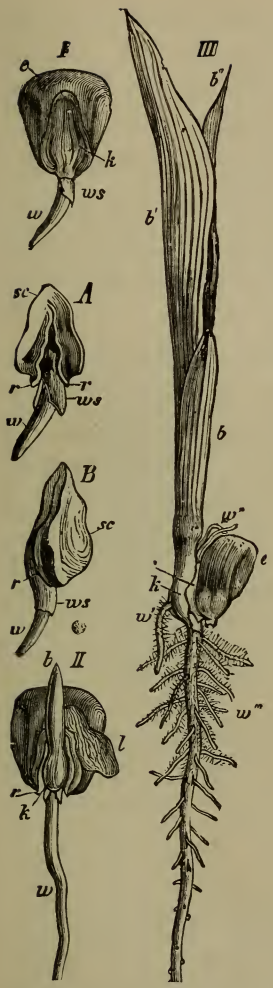


FIG. 158.—Germination of Indian Corn. *I*, *II*, *III*, successive stages. *A* and *B*, front and side views of a separated embryo; *w*, root; *e*, part of seed filled with endosperm; *sc*, cotyledon; *r*, its open margins; *b*, *b'*, *b''*, leaves of young plant; *l*, fragment of wall of ovary. Natural size.

endosperm; anteriorly it is curved entirely around the remainder of the embryo.

505. Under proper conditions the main root pushes through the root-sheath (*ws*, Figs. 157, 158). The plumule, consisting of a minute stem and a few rudimentary leaves, next pushes out through the upper end of the curved cotyledon (*II*, Fig. 158). The cotyledon remains in contact with the endosperm and absorbs nourishment from it for the sustenance of the growing parts. Lateral roots soon appear upon the main root, and adventitious ones arise from the first internodes of the stem (*w'''*, *w''*. *w'*). The first leaf above the cotyledon is quite small (*b*), and each succeeding one becomes larger and larger until the full size is reached.

506. The primitive flower of the Monocotyledons is well illustrated by the Water-plantains, in which the parts are all free from one another. The Lilies show a higher structure in their compound ovary, while in the Irises the inferior ovary marks a still greater advance, which culminates in the Orchids, the highest members of the sub-class. The

flowers of the Aroids and Palms have a structure based upon and but little modified from the lily type, while in Grasses and Sedges are found the extreme modification and simplification of the same type. From the Grasses through the Sedges to the Lilies the gradation is an easy one, while from the Orchids through the Irises the passage is equally easy to the Lilies. We may, perhaps, regard the Lilies as typical Monocotyledons from which the orders diverge to specialized forms.

507. The flowers of most grasses and sedges are wind-pollinated (anemophilous), while those of the Orchids are almost entirely dependent upon insects for pollination. In the grasses we find a great amount of dry powdery pollen, but in the Orchids, on the contrary, the pollen is in small quantity and usually held together by sticky threads. The stigmas of grasses are large, prominent, and generally feathery, so as to easily catch and retain the pollen; in the Orchids, however, they are mostly sticky surfaces, rarely projecting, often much depressed.

508. These differences in the sexual organs are accompanied by similar ones in the surrounding parts. Thus the stamens and pistils in grass-flowers are surrounded by chaffy scales pale or green in color. Such flowers are therefore not conspicuous, although generally clustered at the summit of the stem. Moreover, they possess little or no nectar, and, with few exceptions, are scentless. In the Orchids there is a well-developed perianth which shows high specialization of form and color. Most are provided also with nectar-glands and an attractive odor.

509. In Orchid-flowers the stamens and styles are fused together into a "column" which occupies the centre of the perianth. In the great majority of cases there is but one

anther (representing one stamen), and this is on or near the end of the column, so placed as to be readily touched by an insect entering the flower. The pollen-cells cohere in little sticky masses, which easily adhere to the head, antennæ, or back of an insect.

510. It is an interesting fact that in the ordinary terrestrial Orchids the flower develops in such a way that it must twist upon its ovary in order to attain its proper position

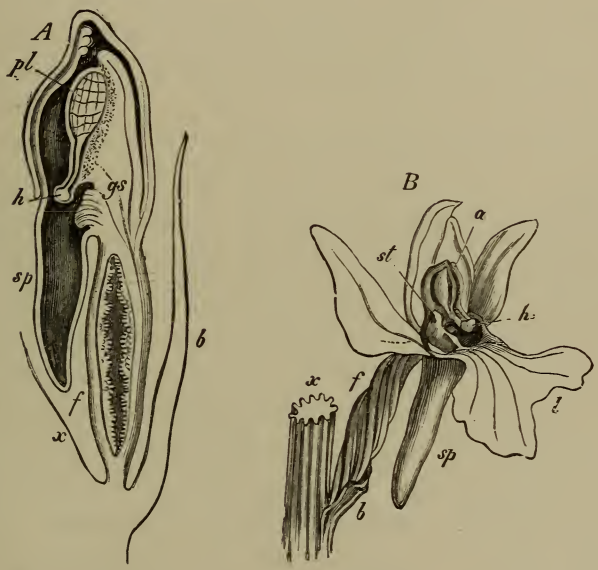


FIG. 159.—An Orchid-flower (Orchis mascula). *A*, vertical section of a flower-bud (magnified) before it has twisted upon its ovary, *f*; *gs*, the column, bearing a pollen-mass, *pl*; *h*, its sticky disk, below which is the stigma. *B*, an open flower; *f*, its twisted ovary; *l*, lip; *st*, stigma; *a*, anther; *h*, its sticky disk; *sp*, spur.

when open (Fig. 159). Thus, without twisting, the lip (*l*) with its spur would be uppermost, while the anther would be below.

511. When a long-tongued insect is attracted to an Orchid-flower by the color and odor, it thrusts its tongue

down into the spur (*sp*) in search of nectar or sweet juices, in the mean time perhaps resting its feet upon the lip (*l*). Its head comes in contact with the sticky disks (at *h*), which adhere tenaciously. When the insect withdraws its tongue, it at the same time carries away the pollen-masses adhering to its head. When the insect visits another Orchid-flower of the same species, the pollen-masses are thrust against the sticky stigma (*st*) and all or a part adheres to it. Thus, as the insect passes from flower to flower, it unconsciously pollinates them, always, however, carrying the pollen of one flower to the stigma of some other.

512. The Lady's-slippers are examples of Orchids with two anthers; these are upon the sides of the curved column which bears the stigma higher up. The lip is here shaped like a slipper (whence the common name), into the opening of which the column bends. The lip and the other parts of the perianth are colored, often showing striking contrasts, and these doubtless serve to attract the notice of insects. When an insect enters the slipper (lip), it does so from the top; but once inside, it finds it difficult to escape by that route on account of the incurved margins of the opening, as well as the smooth sides of the slipper. It accordingly passes backward under the dependent stigma, and escapes by squeezing between the column and base of the slipper: in doing this it covers its back with sticky pollen from the anther on the column. When it visits another flower, this experience is repeated; and as it passes under the stigma in its endeavor to find an exit some of the pollen is left on its surface.

513. Among the tropical Orchids there are some marvellous flowers. One of the most remarkable of these is a

large-flowered species of Catasetum, native of South America. The flowers are diclinous, i.e., the pollen and the ovules are produced in different flowers. The column of the staminate flower is furnished with a pair of slender horns, one or both of which are sensitive. The pollen-masses are curved and in a state of tension, like a curved whalebone spring. Now, when an insect alights on the lip of the flower and comes in contact with one of the sensitive horns, the pollen-mass is instantly set free with a jerk sufficient to throw it nearly a metre, and in such a direction as to strike and adhere to the head of the insect. When the insect visits a pistillate flower, the pollen-mass is in the proper position to be brought in contact with the stigma, thus effecting pollination.

514. Much might be written about these truly wonderful plants, but what has been said must suffice to call the attention of the student to them. Our native species will well repay a careful examination, while the exotic ones, of which hundreds are now grown in conservatories, show a greater variety in form and color of flower than can be found in any other family of plants. The student may profitably read in this connection Mr. Darwin's work, "The Various Contrivances by which Orchids are Fertilized by Insects."

515. The Monocotyledons include many of our finest ornamental plants. Thus some of the grasses and sedges are grown for the beauty of their foliage and flower-clusters, and many aroids find places in greenhouses, one of the most common being the so-called Calla-lily from South Africa. In the Lilies, however, we find the greatest number of plants grown for the beauty and attractiveness of their flowers, possibly excepting the Orchids. Of the

Lilies proper there are many species from America, Europe, Asia Minor, China, and Japan which have long been in cultivation in gardens. Closely allied to these are the Day-lilies and the stately Crown-imperial, the Hyacinth, now of many forms and colors, and the Tulips, which under cultivation have been made to vary still more. The Amaryllids have given us the Snowdrop and Snowflake, the Daffodils, Jonquils, and the delightfully sweet-scented Tuberose. From the Irids we have many species of Iris, Crocus and Gladiolus, the last from South Africa. The use of the Orchids as ornamental plants has already been referred to; but while, doubtless, more species of these are grown, they are for the most part confined to special greenhouses and conservatories called orchid-houses, and are not found in common cultivation among the people at large.

516. The rank of the Monocotyledons economically is high. The seeds of the grasses have a copious starchy endosperm which has for ages been used as food for man and his domestic animals. Thus wheat, rye, barley, oats, and rice, all natives of the old world, have been in cultivation from time immemorial. Indian Corn, being a native of America, has but recently come under general cultivation. The stems of most grasses are nutritious, and constitute the greater part of the pasturage and fodder for domestic animals. In several of the larger species, as the Sugar-canes, this nutritious matter is so abundant as a sweet juice that they furnish the greater part of the sugar of the world.

517. The Palms, while of little value to the people of cooler climates, furnish in tropical regions most of the necessaries of life. In some countries every want of man

is supplied by one or another of the palms. The Cocoa-nut-palm, now grown in all hot climates, is one of the most useful of the species, furnishing material for huts, fences, baskets, buckets, ropes, mats, cups, food, wine, and many other purposes. The Date-palm of the Mediterranean region, the Palmyra Palm of Southern Asia, and the Sago-palms of Siam and the Indian Archipelago are all food-producing trees of great importance to the people of these countries.

518. The Bananas likewise furnish great quantities of food to the natives of tropical countries. There are several

FIG. 160.—Part of a flowering plant of the Banana, showing the unfolding flower-bud and the young fruits.

species and many varieties; all are large herbs with a palm-like aspect, often 3 to 5 metres (10–15 feet) high. Their fruits are borne at the summit of the stem, a large flowering bud gradually unfolding and exposing clusters of small flowers which produce the well-known fruits (Fig. 160).

SUB-CLASS II. **The Dicotyledons** (*Dicotyledoneæ*).

519. The first leaves of the embryo are two and opposite; hence they are said to have two cotyledons. The venation of the leaves is for the most part such that the veins are rarely parallel, and in joining one another they form an irregular network.

520. The germination of Dicotyledons may be illustrated

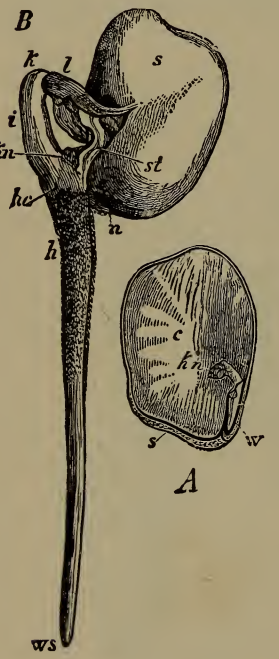


FIG. 161.

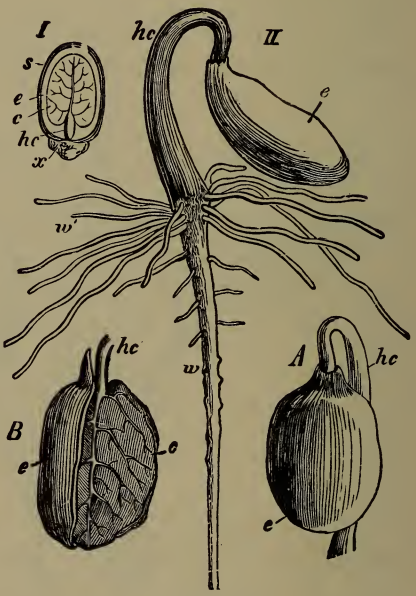


FIG. 162.

FIG. 161.—Windsor Bean (Vicia faba). *A*, seed with one cotyledon removed; *c*, cotyledon; *kn*, plumule; *w*, root; *s*, seed-coat. *B*, germinating seed; *s*, seed-coat, partly torn away at *l*; *st*, stalk of one of the cotyledons; *k*, curved stem above, and *hc*, short stem (hypocotyl) below, the cotyledons; *h*, *ws*, root.

FIG. 162.—Castor-oil Plant (Ricinus communis). *I*, longitudinal section of the ripe seed. *II*, germinating seed with the cotyledons still inside of the seed-coat (shown more distinctly in *A* and *B*). *s*, seed-coat; *e*, endosperm; *c*. cotyledon; *hc*, stem (hypocotyl); *w*, root.

by the following examples. In the seed of the Windsor Bean (Fig. 161) the embryo entirely fills up the seed-cavity,

the endosperm having all been absorbed. The thick cotyledons lie face to face, and are attached below to the small stem of the embryo-plant. The stem extends upward a short distance between the cotyledons, bearing a few rudimentary leaves and itself ending in a growing point, the whole constituting the *plumule*. The downward prolongation of the stem (commonly, but erroneously, called the *radicle*, for it is *not* a little root) ends in a very short root which is continuous with the stem.

521. Under the proper conditions of heat and moisture the root elongates and pushes out through the pore (micropyle) of the seed-coat; at the same time the stalks of the cotyledons elongate and thus bring the plumule outside of the seed-coat, the cotyledons alone remaining within. During the first few days of its growth the young plant is nourished by the starch in the cotyledons, which in this species remain during the whole process of germination beneath the ground enclosed in the seed-coat. In the common Field-bean (Phaseolus) the germination is the same excepting that the stem elongates below the cotyledons and brings the latter above the ground.

522. The seed of the Castor-oil Plant contains a large embryo surrounded by a thin layer of endosperm (Fig 162. *I*). In its germination the root and stem below the cotyledons elongate, and thus bring the seed-coat with the contained cotyledons above the ground (Fig. 162, *II*). The cotyledons remain within the seed-coat until they have absorbed all of the endosperm ; when this is accomplished, the empty seed-coat falls away, and the freed cotyledons expand and assume to some extent the functions of ordinary foliage-leaves.

523. The venation of the leaves of Dicotyledons is easily

studied by macerating them so as to remove the soft tissue, leaving onyl the fibro-vascular bundles. While there is, as a rule, a general likeness between them, there is yet an almost infinite diversity in the details of structure. The general disposition of the smaller veins is well illustrated by Fig. 163.

FIG. 163.—Magnified fragment of a leaf of a Dicotyledon, showing reticulated venation.

524. A great many Dicotyledons show adaptations for pollination by insect agency, and it is safe to say that more than half the species are more or less dependent upon the visits of insects in order that their ovules may be fertilized. In a general way it may be said that the showy flowers with a bright calyx or corolla, or both, are pollinated by insects, while those without showiness are wind-pollinated, or close-fertilized. The plants of the apetalous species are for the most part not visited by insects; few of them have bright colors, and few produce nectar.

525. The simpler Choripetalæ, as the Crowfoots (Fig. 164) and their near allies, attract insects by their showy perianth, and the nectar they secrete. Cross-fertilization is generally secured by a difference in the time of maturity of stamens and pistils (i.e., by dichogamy), apparently, however, often permitting close fertilization. The same is true in general of most of the regular flowered Choripetalæ. Thus in the Roseworts (Fig. 165), while nectar is usually abundant and the flowers are generally sweet-scented as well as showy, their regularity of form prevents

perfect cross-pollination. However, as the flowers are

FIG. 164.—Marsh-marigold (Caltha palustris), with showy yellow perianth.

generally in clusters, it usually happens that the pollen from one flower is carried to the stigmas of another. The attractiveness of the flowers is such that through the visits of great numbers of insects the large amount of pollen is pretty well distributed upon other stigmas.

FIG. 165.—The cherry (Prunus cerasus), with clustered flowers.

526. In the nearly related leguminous plants, as beans, peas, clover, lupines, etc., the perianth is not regular. There are

three forms of petals in each flower, viz., one large broad one, the "banner," two lateral ones, the "wings," and two anterior ones which together form the "keel." These all together form a structure enclosing the stamens and pistil in such a way that an insect cannot get any of the nectar at the base of the corolla without setting free some of the pollen, which adheres to the hairs of its body and is thus carried to the stigma of some other flower.

527. In the Gamopetalæ the union of petals into a tube serves to compel insects to visit the flower in one way only. In the Mints (Fig. 166) the flower is two-lipped,

FIG. 166.—Flower of Dead-nettle, (Lamium) side view and vertical section. Magnified.

the broader lip usually serving as a resting-place for the insect while it thrusts its head or tongue into the corolla. The upper lip is frequently arched so as to contain the stamens and style. In the Dead-nettle the stigma projects beyond the stamens (Fig. 166), so that upon visiting successive flowers the insect always first pollinates the stigma with pollen from preceding flowers, and then, coming in contact with the stamens, secures more pollen. In many plants with a similar structure the stamens mature before

the stigmas are ready for pollination, so that in these, while the means for cross-pollination are perfect, self-fertilization is rendered impossible.

528. In the Compositæ (Fig. 167) the five anthers are united into a ring or tube around the style. The pollen

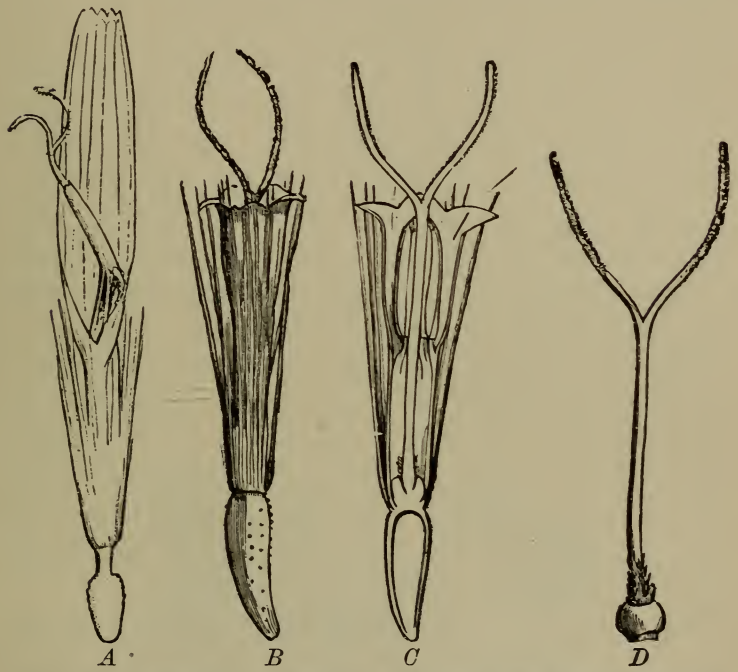


FIG. 167.—Flowers of Composites. *A*, of Dandelion, showing style protruding through rings of anthers; *B*, of Thoroughwort; *C*, ditto, vertical section showing style surrounded by anthers; *D*, style showing two stigmas. All magnified.

escapes from the inner side of the anthers into the anther-tube, and at this time the immature style is short. As the latter grows it pushes up through the anther-ring, carrying the mass of pollen with it. Insects visiting the flowers for nectar at this stage rub off the little piles of pollen from the top of the stamen-tubes, and coming in contact after-

wards with the expanded stigmas of other flowers, some of the pollen is left upon them.

529. After the pollen is set free the style elongates still more, and finally the two lobes of the stigma open out and are ready for pollination. This development takes place beginning at the outer rows of flowers in each flower-head and proceeds towards the centre. Thus at any time in any blooming flower-head, as of the Sunflower, there may be seen a ring of pollen-bearing flowers and outside of it a ring of flowers with expanded stigmas. In some Composites, in addition to these structural peculiarities, the stamens are sensitive, and when touched will suddenly contract, drawing the anther-tube down and ejecting pollen. This may easily be seen by passing the finger quickly across the top of a thistle-head when in full bloom.

530. The foregoing must serve to direct the student to the careful observation of the flowers of Dicotyledons. He should remember Lubbock's remark that "it is probable that all flowers which have an irregular corolla are pollinated by insects," and to this he may well add that it is equally probable that all tubular flowers which open their lobes are likewise pollinated by insects.

531. Among the interesting things to which attention has been directed during the past few years is that of the insectivorous habits of certain plants. Here again no more than a fragment can be given, barely enough to introduce the student to the subject.

532. Many plants catch insects by means of their sticky glandular hairs, or glandular surfaces upon their stems or leaves. This may be readily seen by examining a petunia- or tomato-stem, or the sticky belts on the stems of various species of Catchfly, or the sticky spots on the bracts sur-

rounding the flower-heads of some thistles. Whether the small insects thus caught are made use of by the plants in any way is as yet uncertain.

533. In the Sundews (Fig. 168), which are common little bog-plants, the leaves have many stalked glands which

FIG. 168.—A Sundew-plant (Drosera). Natural size.

secrete a sticky substance. These glands are sensitive, and when an insect comes in contact with one or more of them and is held fast the others slowly bend towards the insect, and the leaf itself rolls up, completely surrounding the

unfortunate victim. An acid fluid is produced by the glands, and by this the insect is dissolved and afterwards absorbed by the leaf-tissues. In midsummer it is no un-

FIG. 169.—The Carolina Fly-trap (Dionæa muscipula). About natural size.

common thing to find several of these leaves with insects upon them.

534. The Carolina Fly-trap (Fig. 169), or Venus's Fly-trap, as it is frequently called, is one of the most remarkable

plants known. It is a native of a small district near Wilmington, North Carolina, but is now grown frequently as a curiosity in conservatories. Each leaf has a rounded blade fringed on the sides with a row of stiff points or spines. Upon each half of the leaf there are generally three sensitive hairs, and when these are touched the sides quickly close together, and the stiff marginal spines interlock like the teeth of a rat-trap. "The upper surface of the leaf is thickly studded with minute glands of a reddish or purplish color" (Darwin). These secrete an acid fluid which has the power of digesting insects and other nitrogenous matters. When an insect happens to alight upon a leaf and touches one of the sensitive hairs, the trap closes so quickly upon it that it is almost invariably caught and securely held, its struggles only serving to increase the vigor of the grasp in which it is held. After a while the digestive fluid is poured out by the glands, and in this the insect is gradually dissolved. In this way the leaf-tissues absorb the insect, and are doubtless nourished by it. After a time a leaf which has caught and digested an insect opens again and is ready for another. In this connection the student may profitably read Mr. Darwin's interesting book, "Insectivorous Plants," published in 1875.

535. A quite different class of insect-catching plants is represented by the Pitcher-plants of various kinds. In the common Pitcher-plant, which grows in marshes in the northern and eastern United States, the leaves are dilated into tubular or pitcher-shaped cavities (Fig. 170), containing a watery fluid. The upper part of the leaf is reddish in color, and doubtless this attracts insects, Moreover, this upper part is covered with minute stiff hairs, which point downward; they also cover the upper part of the

inner surface of the cavity, and probably have not a little to do with the entrance of insects into the fatal pitcher. However this may be, many insects are found drowned, and in all stages of decomposition, in the fluid in the pitchers. Other species in the Southern States have a lid-like cover which prevents the entrance of rain, and in

FIG. 170.

FIG. 171.

FIG. 170.—Common Pitcher-plant (Sarracenia purpurea), showing leaves and flower; one leaf cut across so as to show the cavity. Half natural size.

FIG. 171.—The California Pitcher-plant (Darlingtonia californica), showing leaves and a flower. About one seventh natural size.

some species drops of nectar have been found upon the outside of the pitcher, forming a trail to lure insects to its edge.

536. The California Pitcher-plant (Fig. 171) resembles the foregoing, but its arched leaves have a curious forked appendage hanging down from the edge of the orifice, which is here on the under side of the arch. This appendage is more or less covered with a sweet secretion which lures insects. Probably this is made more effective by the reddish or purplish color of the appendage, giving it at a distance no little resemblance to a flower. The watery fluid inside of the leaf always contains the remains of many insects.

537. An Australian plant related to the Saxifrages produces remarkable pitchers. It is a low plant with a rosette

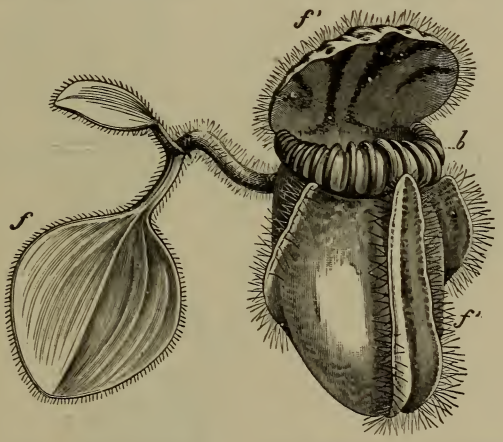


FIG. 172.—Leaves of Australian Pitcher-plant (Cephalotus). Natural size.

of leaves upon the ground; some of these resemble the covered pipes used by many Frenchmen (Fig. 172). The border of the pitcher is incurved and presents an obstacle to the egress of insects, which are no doubt thus captured.

538. Various species of Nepenthes (Fig. 173) occur in the East Indies. The leaves are prolonged into a slender

tendril-like organ, upon whose extremity there develops a hollow closed body, which finally becomes open by the separation of a hinged lid (Fig. 173, *d*, *e*, *f*). In the

FIG. 173.—Two leaves of Nepenthes, the Indian Pitcher-leaf. *f*, the lid, which is still closed in the younger leaf. Reduced.

cavities of these pitchers a watery, slightly acid fluid is secreted; upon their borders are secreted honey- or nectar-drops, which attract insects, and these falling into the

fluid within are soon dissolved by it, and then absorbed by the plant for its nourishment.

539. There is a close connection between the ornamental value of a plant and the perfection of its flower as a mechanism to secure pollination by means of insects. In other words, those things in a flower which are attractive to insects are, as a rule, attractive to us also. Thus the large, brightly colored perianth and the sweet scent of the wild rose, which serves to secure the visits of insects, are likewise attractive to us.

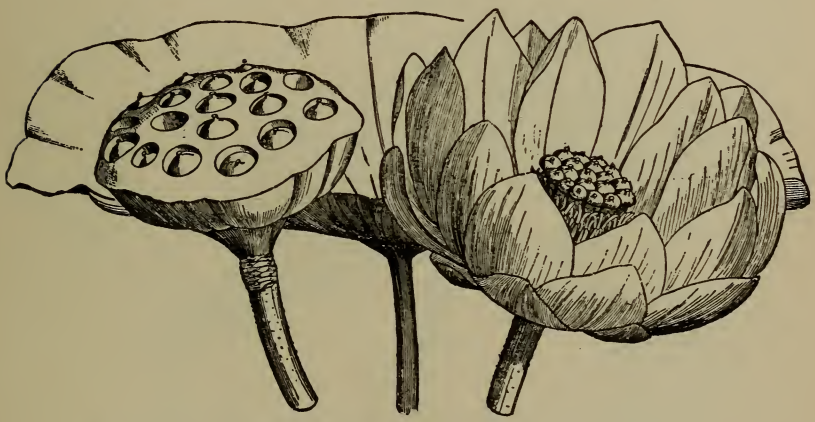


FIG. 174.—A water-lily (Nelumbo lutea). One third natural size.

540. The apetalous plants are thus of low ornamental value in so far as their flowers are concerned. The gamopetalous and polypetalous (choripetalous) species furnish many fine flowers which have long been favorite ornaments in gardens and conservatories. Thus the Verbenas, Phloxes, Heliotropes, Primroses, Azaleas, Rhododendrons, Heaths, Bellflowers, Honeysuckles, and great numbers of Composites may be taken to represent the ornamental

members of the Gamopetalæ. And so the Passion-flowers, Roses, Lupines, Wistarias, Mallows, Camellias, Pinks, Violets, Mignonettes, Poppies, Water-lilies, Buttercups, and Columbines may be taken as representatives of the ornamental Choripetalæ.

541. Economically the Dicotyledons are of very great importance to civilized man. Thus valuable timber trees occur among the Magnolias, Tulip-trees, Willows, Poplars, Lindens, Elms, Hackberries, Plane-trees, Maples, Walnuts, Hickories, Oaks, Beeches, Chestnuts, Birches, Ashes, and

FIG. 175.—Flower-cluster of the Pear (Pirus communis).

Catalpas. Food-products are supplied by Turnips, Radishes, Cabbage, Buckwheat, Apples, Pears, Strawberries, Blackberries, Raspberries, Plums, Peaches, Cherries, Beans, Peas, Cucumbers, Melons, Squashes, Pumpkins, Grapes, Parsnips, Carrots, Huckleberries, Cranberries, Olives, Sweet Potatoes, Potatoes, Tomatoes, Coffee, Artichokes. To the Dicotyledons also the world is indebted for that exceedingly valuable substance India-rubber, which is obtained from the milky juice of several tropical trees

related to the Nettles and the Spurges, as well as for flax and cotton, two of the most important fibres in the world,

FIG. 176.—Flax.

FIG. 177.—Potato.

and the two drugs of greatest value medicinally, viz., opium and quinine.

CHAPTER XIII.

PRACTICAL STUDIES IN THE GROSS ANATOMY OF THE ANGIOSPERMS.

INTRODUCTION.

542. THESE "studies" are designed to be used as a guide in the actual study of the gross anatomy of plants, and the teacher is implored not to require pupils to memorize them for recitation. Let it be borne in mind that Botany is the study of *plants*, not the study of *books*. Let this chapter be a guide, and nothing more.

543. It is suggested that the pupil should make a complete examination of a plant, following the order given, and making a careful record of his observations. The descriptive terms commonly used in manuals of botany are introduced for the use of the pupil in making his record, and with these he should familiarize himself as soon as possible. The pupil may now be examined upon the structure of the plant he has studied, and may be required to define the descriptive terms he has used in his work. However, the teacher is again warned not to require a memorizing of these terms before the pupil has made their acquaintance by actual examination.

544. A dozen plants carefully examined throughout should make the pupil sufficiently familiar with the gross anatomy of angiosperms, and the common terms used in descriptive botany so that any of the ordinary systematic

manuals may be readily used. But it must be insisted that the work must be *thoroughly* done. A hasty and careless running through the pages, with plant in hand, will not help the pupil. The work must be slow, careful, and conscientious. And the pupil must bring to his work the determination to acquire as quickly as possible the power of close observation and accurate description. While he is forbidden to memorize descriptive terms while they are meaningless to him, yet he is expected never to forget a form once seen and its appropriate descriptive term.

545. The following plants are recommended for study:

Blossoming in the spring and early summer:
Tulip, Buttercup, Hepatica, Violet, Cherry, Apple, Weigelia, Lilac, Pea, Rye.

Blossoming in the summer and autumn:
Lily, Bouncing Bet, Morning-glory, Petunia, Buckwheat, Indian Corn, Sunflower, Golden-rod, Gentian.

546. Select a well-grown specimen of any plant, preferably in its flowering and fruiting stage, and make a study of all its parts in the following order:

Axis, composed of
- (1) Stem, which bears
  - (3) Leaves;
  - (4) Buds;
  - (5) Flowers;
  - (6) Fruits;
  - (7) Seeds.
- (2) Root.

Record your observations neatly and concisely, making drawings or outline sketches of the more important parts.

§ 1. The Stem.

Form.—Most stems are *cylindrical*, or nearly so, in form, while others are *flattened*, *square*, *triangular*, etc.

Size.—Measure the diameter and height of the stem, using preferably the metric scale.

Surface.—Many stems are *smooth*, especially when young; but as they grow older they generally become more or less *roughened*. They may be irregularly roughened, as in many tree-trunks, or they may be somewhat regularly *furrowed*. Many stems are *hairy*, the degrees being noted as *downy* (when soft and not abundant); *silky* (when close and glossy); *villous* (when long and spreading); *hispid* (when short and stiff), etc. Other appendages of the surface are *prickles*, *warts*, *scales*, etc.

Color.—Note the color of the surface of all parts of the stem, including the branches and twigs.

Structure.—In some stems the softer tissues predominate; these are *herbaceous*, and the plants are *herbs*. In others the harder tissues predominate; these are *woody* or *ligneous* plants, and are either *shrubs* (which are not more than a couple of metres in height, and generally have more than one stem) or *trees* (which have a single

FIG. 178.

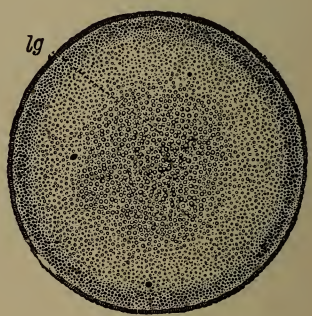


FIG. 179.

FIG. 178.—Cross section of the stem of an oak-tree thirty-seven years old, showing the annual rings. *rm*, the medullary rays; *m*, the pith (medulla).

FIG. 179.—Cross section of the stem of a palm-tree, showing the scattered bundles.

stem, and often attain the height of many metres). It must be remembered that intermediate forms of all degrees occur between herbs and shrubs, herbs and trees, and shrubs and trees.

Duration.—Some stems live for but one season, and are known as *annual;* others live for two seasons (gathering food the first, and producing flowers and seeds the second), these are *biennial;* those which live for several or many years are *perennial.*

Branching.—Most stems branch more or less, generally *irregularly*, rarely *regularly;* the latter may be *scattered*, *alternate*, *opposite*, or *whorled* (i.e., three or more in a circle around the stem).

The Bark.—With a sharp knife dissect the bark of a twig, noticing—1st. The thin outer part, the *epidermis.* 2d. A soft layer beneath it, the *soft bark* (which is entirely green, or partly green and partly colored, or more or less corky). 3d. A layer of *fibrous bark,* often called *bast.* Dissect the bark of older parts of the stem and notice the disappearance of the epidermis and the soft bark. The fibrous bark has here become intermingled with more or less corky matter, and has been ruptured into scales, ridges, and furrows.

The Wood.—I. With a sharp knife cut across the stem and examine the portion inside of the bark. If of a stem several years old, it will probably show several more or less well-defined *annual rings* (Fig. 178). Notice that the rings are marked and defined by belts of *ducts* (pores) which constitute the "grain" of the wood. In the centre is the *pith,* from which there extend toward or to the bark narrow radiating lines—the *medullary rays* (*rm*).

II. In some plants there is no distinction of wood and bark, as in the canes. In such there are no annual rings, nor are there any medullary rays. The ducts and their surrounding wood occur in scattered independent bundles which may be loosely or closely packed (Fig. 179), producing a spongy stem (as in some palms, Indian corn, etc.), or a dense one (as in the canes, rattan, etc.).

III. In many herbaceous plants the wood is in a narrow ring, or in a number of separate woody bundles which are arranged more or less exactly *in a circle* (Fig. 180). In soft plants the bundles are often very small and difficult to see.

FIG. 180.—Cross-section of the herbaceous stem of a Candytuft (Iberis), showing the bundles arranged in a circle.

Plants whose wood is arranged in a circle, or which have annual rings, usually have two cotyledons in their embryos, and are known as Dicotyledons (Figs. 178 and 180), while those whose woody bundles are independent and scattered and which have no proper bark or pith, usually have but one cotyledon, and are known as Monocotyledons (Fig. 179).

Underground Stems.—The student must not overlook the stems which grow under the surface of the ground. They may generally be distinguished from roots by the scales or buds which they bear. A common form is the *rootstock,* common in many of the grasses and sedges as well as in numerous other plants. Some underground stems are much thickened, and are called *tubers,* as in the potato, where the "eyes" are in reality the buds of the thick stem. In the *corm* the short thickened stem stands vertically and is coated with

thin scales, as in Gladiolus. In the *bulb* the short stem (usually not much thickened) is covered with thickened scales, as in the onion.

§ 2. The Root.

Form.—Most roots are *cylindrical*, or nearly so, in form. When of this form and quite small, they are *thread-like* (*filiform* or *fibrous*). Many fleshy roots are *conical* (Fig. 181); others are *spindle-shaped* (*fusiform*), as Fig. 182; and still others are *turnip-shaped* (*napiform*), Fig. 183. When a main root extends perpendicularly downward from the plant, it is called a *tap-root*.

Fig. 181. Conical root.

Fig. 182. Spindle-shaped root.

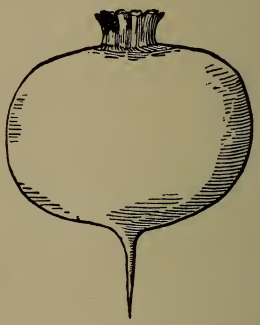


Fig. 183. Turnip-shaped root.

Size.—Make measurements of the root as for the stem.

Surface.—Examine the surface of the smallest roots: observe the very minute down-like *root-hairs*. The surface of the large rootlets is smooth; then as the roots grow older the surface becomes more or less roughened.

Color.—While the youngest rootlets are usually white, as they grow older they generally become yellowish or brownish on the surface.

Structure.—Roots may be *soft* in structure, or they may be *woody;* the former may be *fleshy*, as in the turnip, or *thread-like*, as in wheat and oats. The wood and bark resemble those of the stem, but the

pith is wanting. Examine the tip of the root and notice the blunt end, which, under a lens, shows a root-cap.

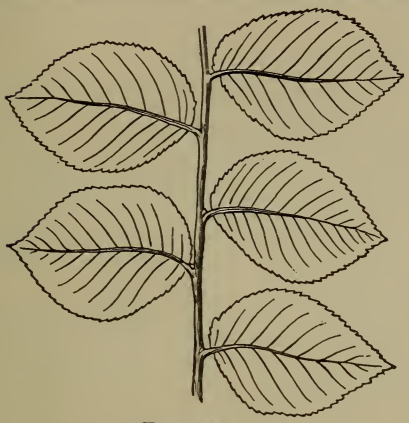


FIG. 184.
Scattered or alternate leaves.

FIG. 185.
Opposite leaves.

Duration.—Many annual-stemmed plants have *annual* roots; others which have annual stems have *biennial* or *perennial* roots. In

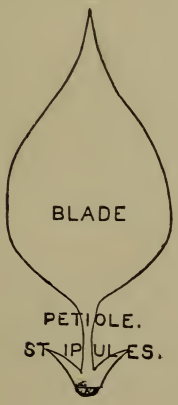


FIG. 186.

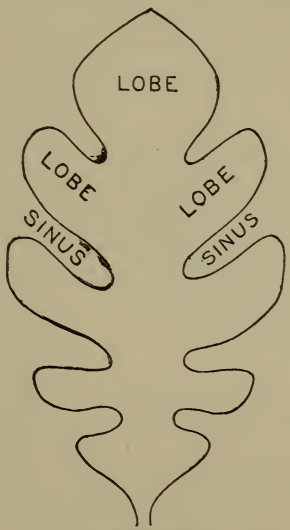


FIG. 187.

FIG. 186.—Diagram showing parts of leaf.
FIG. 187.—Diagram of lobed leaf (pinnately lobed) showing lobes and sinuses.

shrubs and trees the roots are of course perennial. Many rootlets, however, even in trees and shrubs, die off in the autumn, and new ones are produced in the spring.

Branching.—The branching of roots is usually very irregular. Where roots are branched, the main root is called the *primary root*, while its branches are *secondary roots*. In examining the branches of roots, notice that they spring from beneath the surface of the main root. In this they differ from the branches of stems. In stems the surface of the main stem is continuous with that of its branches, but in roots the surface is broken at the points where branches emerge.

§ 3. The Leaf.

Position on the Stem.—Leaves grow upon the stem in several ways. In some cases they are *scattered* (or *alternate* Fig. 184); in others they are *opposite* (Fig. 185); in others again they are *whorled* (i.e., several occupy a circle around the stem).

Parts.—Many leaves have three well-defined parts: 1. A broad or flattened part, the *blade;* 2. A leaf-stalk, upon which the blade is supported, the *petiole;* 3. Two little appendages or lobes at or near the base of the petiole, the *stipules*. (Fig. 186.)

Blade.—The blade is always one piece when the leaf is very young (i.e., very early in its growth in the bud). In many cases it remains so in all its subsequent growth, and is said to be *simple*. Very commonly, however, even in simple leaves the blade has branched more or less in its growth, giving rise to *lobes* of various sizes and forms (the *lobed* leaf). The indentation between two lobes is termed a *sinus* (Fig. 187). When the branching is so profound that the lobes have become separable leaflets, the blade is said to be *compound*.

Fig. 188.—Radiately or palmately lobed leaf.

The branches of the blade may radiate from a common central point (*radiately lobed, radiately compound*, or, more commonly, *palmately lobed*, Fig. 188, *palmately compound*, Fig. 189); or they may grow out on opposite sides of an axial portion (*pinnately lobed*, Fig. 187, *pinnately compound*, Fig. 190). Leaf-branches may branch again; thus we may have *twice palmately lobed* and *twice palmately compound leaves*, and likewise *twice pinnately lobed, twice pinnately compound leaves*, etc., etc.

Forms of Blade.—The forms of the blade may be concisely arranged as follows (Fig. 191):

1. *Round* (orbicular), with a circular outline, or nearly so.

2. *Ovate*, which is longer than broad, and has a broader base and a narrower apex (the reverse of this is the *obovate*). When the base

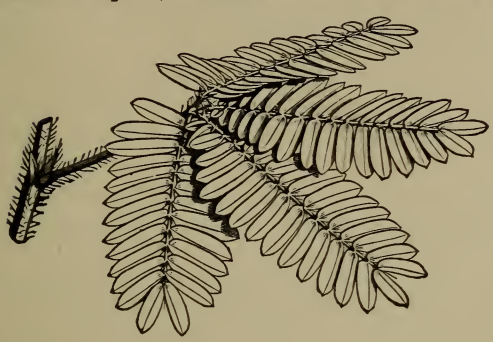


FIG. 189.

FIG. 190.

FIG. 189.—Radiately or palmately compound leaf.
FIG. 190.—Pinnately compound leaf.

is divided into two rounded lobes, the leaf is *heart-shaped*. Related to the ovate is the *rhombic* leaf with more or less angled sides. The *triangular* leaf is another modification in which the base is *truncate*

FIG. 191.—Types of leaf-forms.

(cut off). The very short and broad modification of the heart-shaped blade is the *kidney-shaped* leaf (reniform). The narrow ovate is the *lanceolate* form, while its reverse is the *oblanceolate* (spatulate).

3. *Elliptical*, which is longer than broad, has base and apex equal, and sides rounded.

4. *Oblong*, which is two to three times longer than broad, with straight, parallel sides. Varieties of this are the *linear*, which is very narrow and long: when this is rigid and sharp at the apex, it is the *needle-shaped* leaf; when small and thread-like, it is *capillary*.

5. *Oblique:* any of the foregoing forms in which one side has become broader than the other; thus, *obliquely ovate, obliquely heart-shaped*, etc.

The Base and Apex.—In most leaves two extremities may be distinguished and described. There are three general forms, viz., the acute, obtuse, and notched. (Fig. 192.)

The extremity is *acute* when the approaching sides form an acute angle with each other. When the acute extremity is prolonged, it is *acuminate*. When the apex ends in a bristle, it is *cuspidate*.

The extremity is *obtuse* when blunt or rounded. When so blunt as to seem as if cut off, it is *truncate*, as in what is known as the wedge-shaped (*cuneiform*) leaf. In some cases a point or bristle grows from the obtuse apex; such are said to be *mucronate*.

The extremity when indented is *notched* or *emarginate:* when this is slight, it is *retuse;* when so deep from the apex as to appear

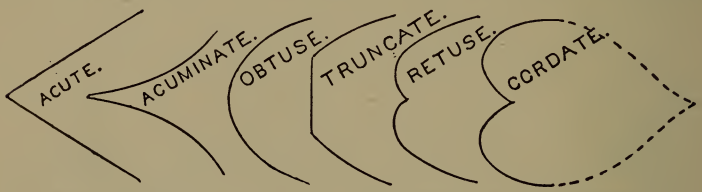


FIG. 192.—Diagrams of the principal forms of base and apex.

cleft, the leaf is *bifid*. A common form of emarginate apex is seen in the *obcordate* (i.e., inversely heart-shaped) leaf, while the emarginate base is found in the *cordate* (i.e., heart-shaped) leaf. The notch in the base of a leaf is also known as a *sinus*.

Margin of the Blade.—When the growth of the leaf has been uniform throughout, its margin is an even and continuous line, and the blade is said to be *entire*. More commonly there are inequalities in the growth; when these are rounded and not great, the margin may be *wavy*, or if somewhat more, *sinuate*, which readily passes into the *lobed* form, with the projections (*lobes*) and the indentations (*sinuses*) both rounded. (Fig. 193.)

In some cases the projections alone are rounded, the sinuses being narrow as if cut. When such projections are small, the blade is

said to be *crenate* (scalloped); when they are large, *cleft-lobed*, or *cleft*. (Fig. 193.)

When the projections are pointed and small, the blade is said to be *serrated* (saw-toothed); when larger and standing out from the mar-

FIG. 193.—Diagram showing the principal forms of margin.

gin, *dentate* (toothed); when still larger, *incised*. (Fig. 193.) When the projections are hardened and sharp-pointed, the leaf is *spiny*.

Venation of the Blade.—The framework of fibro-vascular bundles (*veins*) running through the leaf always conforms to the general

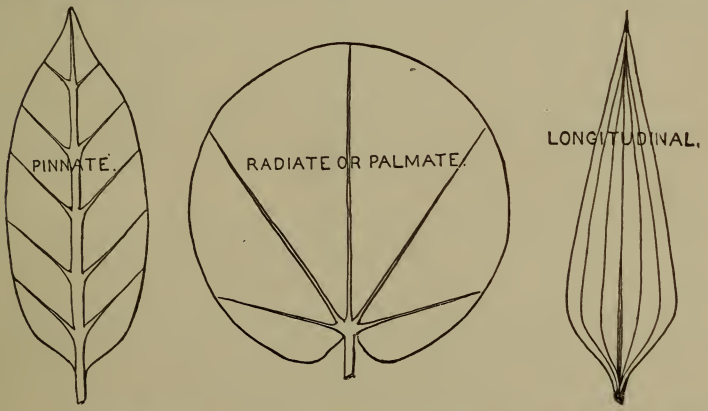


FIG. 194.—Diagram showing principal kinds of venation.

and particular outlines of the blade. There is commonly a mid-vein (*midrib*) running centrally from base to apex, and secondary ones which run centrally (or nearly so) through the lobes. We have thus a *pinnate* venation, in pinnately lobed leaves, and *radiate* venation, in radiately lobed leaves. Moreover, a modified form of

the pinnate or the radiate venation usually occurs in leaves which are not lobed. In grasses, sedges, and many other Monocotyledons the venation is *longitudinal.* (Fig. 194.)

The leaves of most Monocotyledons have their principal as well as subsidiary veins more or less parallel, while in Dicotyledons the subsidiary veins are mostly disposed in a net-like manner; the former are hence called *parallel-veined*, and the latter *netted veined*, leaves.

Size of the Blade.—The length and width of a blade of average size should be measured, and when there is great diversity in size the extremes should also be noted.

Surface of the Blade.—The principal varieties of surface are the following:

1. *Smooth*, when there are no sensible projections or depressions, as hairs, warts, pits, etc., upon the surface. Sometimes a smooth surface is *shining;* in some cases (e.g., the cabbage) it is covered with a fine whitish, floury substance (*bloom*), and is then said to be *glaucous.*

2. *Rough*, when covered with raised dots or points.

3. *Hairy* (pubescent), when the whole surface is more or less covered with hairs. The hairs are sometimes fine and soft, forming a white, glossy covering as in the *silky* surface. When the hairs are long, soft, and spreading, the surface is *villous;* when short and stiff, it is *hispid.* In some cases the hairs are confined to the margin of the blade, when it is said to be *ciliate.*

Color of the Blade.—This is usually green, the particular shade being indicated as green, light green, dark green, etc. Note carefully the difference in color (often due to hairs, etc.) between the upper and under surfaces.

Texture of the Blade.—Most leaves are thin and have a firm texture (*membranaceous*); when tough and leathery, they are *coriaceous.* Leaves of a considerable thickness are *fleshy* or *succulent.*

The Petiole.—The length, shape, surface, and color of the petiole should be carefully noted. Make similar notes also upon the "partial petioles" (i.e., the petioles of the leaflets) of compound leaves.

The Stipules.—These usually consist of small lobes which grow out from near the base of the petiole. Sometimes they are more or less attached to the stem, in some instances sheathing it, as in the buckwheat, where they have united into a single sheath.

In all cases note (*a*) position, (*b*) shape, (*c*) size, (*d*) surface, and (*e*) color of the stipules.

§ 4. The Bud.

Position.—With respect to position upon a twig, buds are *terminal* or *lateral;* and from the fact that the latter grow conspicuously in the axils of leaves (i.e., in the upper angle formed by the leaf with the twig) they are also known as *axillary* buds. Strictly speaking, every bud is terminal, for the so-called lateral buds are in reality terminal upon very short lateral branches of the twig.

Form.—In form most buds are *ovate;* that is, egg-shaped. They are commonly *blunt* at the apex, but may be *tapering.*

Less commonly buds are *spherical,* or nearly so, and occasionally they are *cylindrical.*

If a cross-section be made of a bud, it is usually rounded; but it may be *compressed* (i.e., flattened parallel to its axis) or *angular* (triangular, quadrangular, etc.).

Size.—Measure the length from base to apex, and the diameter through the thickest part.

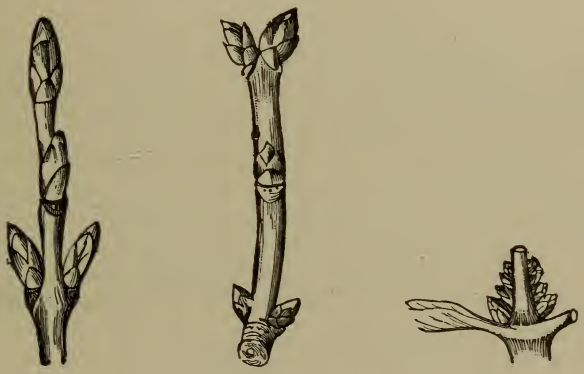


Fig. 195.—Scaly buds of various kinds. At 3 are shown buds clustered in axils of the leaves.

Surface.—With respect to their surfaces, buds are for the most part termed *scaly,* and this term is used especially when the scales are large or somewhat separated from one another.

Many buds are covered externally with a more or less dense coat of hairs (*hairy* buds) or down (*downy* buds).

Some buds are *smooth,* the scales themselves having a smooth surface, and the latter being arranged into an even surface.

For protection against too great loss of moisture from within, and perhaps too great access of moisture from without, many buds are covered with a thin coat of varnish (*varnished* buds), or they may be *waxy,* or even *glutinous* (i.e., somewhat sticky).

Color.—Buds when fully ripened are most commonly brown or brownish in color, but may be black, gray, red, rusty (ferruginous), etc., etc.

Structure.—Dissect several buds, carefully removing the scales one by one, and preserving them as a series. Notice that the outermost ones are usually the hardest, and that as we pass to the inner ones the texture is gradually softer and more like that of young leaves. Notice that the interior is composed of young leaves (or young flowers).

With a very sharp knife split a bud from base to apex, and notice the arrangement of the scales and young leaves (or young flowers) upon the little stem (axis).

Cut a bud across (cross-section), and notice again the arrangement of the parts. Notice particularly the manner of folding (*vernation*) of the young leaves in the bud.

§ 5. The Flower.

INFLORESCENCE.

Types of Inflorescence.—In the study of the flowers of a plant we must first consider their arrangement, i.e., Inflorescence. There are two principal kinds of inflorescence, the *racemose* and the *cymose*. In the first the flowers are always lateral as to the principal axis or axes of the flower-cluster; in the second every axis, principal and secondary, terminates with a flower. In either arrangement each flower may be upon a flower-stalk (*pedicel*) of greater or less length, or the stalk may be wanting, when the flower is *sessile*. In some cases of compound inflorescence the branching is partly of one type and partly of the other; such cases may be considered examples of *mixed* inflorescence.

Kinds of Inflorescence.—The most important of the forms commonly met are given in the following table of inflorescences:

A. RACEMOSE OR BOTRYOSE INFLORESCENCES.

I. Flowers solitary in the axils of the leaves
—e.g., Vinca..... .....Solitary Axillary.

II. Flowers in simple groups. (Fig. 196.)

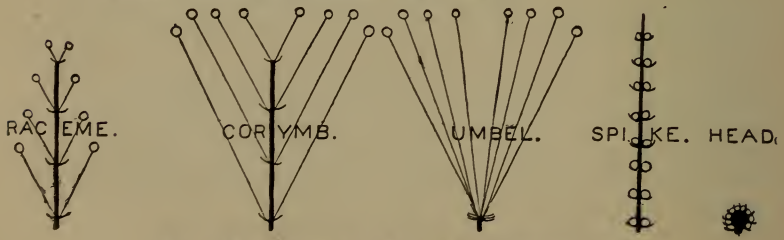


Fig. 196.—Diagrams of racemose inflorescences.

1. Pedicellate.
   (*a*) On an elongated axis ; pedicels about equal—
   e.g., Mignonette.....RACEME.
   (*b*) On a shorter axis ; lower pedicels longer—e.g.,
   Hawthorn.....CORYMB.
   (*c*) On a very short axis ; pedicels about equal—
   e.g., Cherry.....UMBEL.
2. Sessile.
   (*a*) On an elongated axis—e.g., Plantain.....SPIKE.
   Var. 2. Drooping—e.g., Poplar.....*Catkin.*
   Var. 3. Thick and fleshy — e.g., Indian
   Turnip.....*Spadix.*
   (*b*) On a very short axis—e.g., Clover.....HEAD.

III. Flowers in compound groups.
1. Regular.
   (*a*) Racemes in a raceme—e.g., Smilacina .....COMPOUND RACEEM.
   (*b*) Spikes in a spike—e.g., Wheat.....COMPOUND SPIKE.
   (*c*) Umbels in an umbel—e.g., Parsnip.COMPOUND UMBEL.
   (*d*) Heads in a raceme—e.g., Ambrosia..HEADS RACEMOSE.
   (*e*) Heads in a spike—e.g., Blazing Star...HEADS SPICATE.
   And so on.
2. Irregular.
   Racemosely or corymbosely compound—e.g., Catalpa .....PANICLE.

Compound forms of the panicle itself are common—e.g., *panicled heads* in many Compositæ, *panicled spikes* in many grasses.

B. CYMOSE INFLORESCENCES.

I. Flowers solitary ; terminal—e.g., Anemone quinquefolia.....SOLITARY TERMINAL.
II. Flowers in clusters (Cymes). (Fig. 197.)

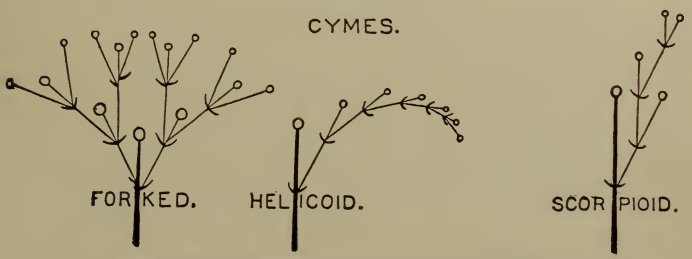


FIG. 197.—Diagrams of three forms of cymes.

1. Lateral branches in all parts of the flower-cluster developed—e.g., Cerastium... ....FORKED CYME.
2. Some of the lateral branches regularly suppressed.
   (*a*) The suppression all on one side—e.g., Hemerocallis.....HELICOID CYME.
   (*b*) The suppression alternately on one side and the other—e.g., Drosera..SCORPIOID CYME.

(The last two are frequently called *False Racemes.*)

C. MIXED INFLORESCENCES.

1. *Cymo-Botryose*, in which the primary inflorescence is botryose, while the secondary is cymose, as in Horse-chestnut..... .....CYMO-BOTRYS.

(This is sometimes called a *Thyrsus.*)

2. *Botryo-Cymose*, in which the primary inflorescence is cymose, while the secondary is botryose—e.g., in many Compositæ.....BOTRY-CYME.

In addition to noting the kind of inflorescence, examine and describe the bracts (small leaves), pedicels, and larger branches of the flower cluster, noting their shape, size, surface, and color.

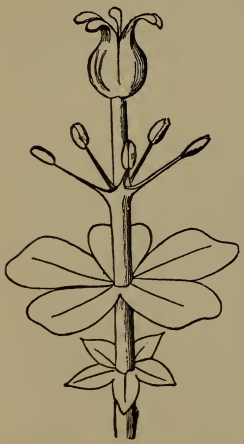


FIG. 198.—Diagram to show the four floral whorls; the lowermost, the sepals, composing the calyx; the next the petals, composing the corolla; the next the stamens, composing the androecium; the uppermost the pistils, composing the gynœcium.

FLORAL SYMMETRY.

Floral Whorls.—The parts of the flower are mostly arranged in whorls or cycles, distinctly separated from each other (*cyclic* flowers); in some cases they are arranged in spirals, with, however, a distinct separation of the different groups of organs (*hemicyclic* flowers); in still other cases the arrangement is spiral throughout, with no separation of the groups of organs (*acyclic* flowers).

In cyclic flowers there are most frequently four or five whorls, viz. (Fig. 198):

1. The *Calyx*, composed of (mostly) green *sepals.*

2. The *Corolla*, composed of (mostly) colored *petals.* The calyx and corolla may be spoken of collectively as the *perianth.* This term is used also when but one whorl of floral leaves, or a portion of it only, is present.

3. (4.) The *Andrœcium*, composed of one or two whorls of *stamens.*

4 or 5. The *Gynœcium*, composed of the *pistil* or *pistils.*

These whorls usually contain definite numbers of organs in each; in many cases the numbers are the same for all the whorls of the flower (*isomerous* flower); when the numbers are different, the flower is said to be *heteromerous*.

The terms which denote these numerical relations are: *monocyclic*, applied to a flower having only one cycle; *bicyclic*, two cycles; *tricyclic*, three cycles; *tetracyclic*, four cycles; *pentacyclic*, five cycles, etc.; *monomerous*, applied to flowers each cycle of which contains one member; *dimerous*, two members; *trimerous*, three members; *tetramerous*, four members; *pentamerous*, five members, etc.

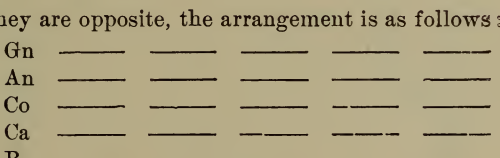
Floral Formulæ.—These relations can be briefly indicated by using symbols and constructing floral formulæ, as follows:

Ca_5, Co_5, An_5, Gn_5 = a tetracyclic pentamerous flower;
Ca_3, Co_3, An_{3+3}, Gn_3 = a pentacyclic trimerous flower.

Most commonly the members of one whorl *alternate* with those of the whorls next above and below; in a few cases, however, they are *opposite* (or superposed) to each other.

Floral Diagrams.—These relations may be indicated by a modification of the floral formulæ given above, as follows, where the members are alternate:

When they are opposite, the arrangement is as follows:



In both these diagrams the position of the parts of the flower with respect to the flowering axis is indicated by the position of the bract B, which is always on the anterior side, while the axis is always posterior.

Symmetrical Flowers.—When all the members on each whorl are equally developed, having the same size and form, the flower may be vertically bisected in any plane into two equal and similar halves; it is then *actinomorphic* (= regular and polysymmetrical, Fig. 199). When the members in each whorl are unlike in size and form, and the flower is capable of bisection in only one plane, it is *zygomorphic*

(= irregular and monosymmetrical, Fig. 200). In the latter there is generally more or less of an *abortion* of certain parts; i.e., one or more of the sepals, petals, stamens, or pistils are but partially developed, appearing in the flower as rudiments only. Sometimes this is so marked as to result in the complete *suppression* of certain parts.

Suppression of Parts.—It not infrequently happens in both actinomorphic and zygomorphic flowers that entire whorls are suppressed; this gives rise to a number of terms, as follows:

When all the whorls are present (not necessarily, however, *all members* of all the whorls) the flower is said to be *complete;* when one or more of the whorls are suppressed, the flower is *incomplete.*

FIG. 199.

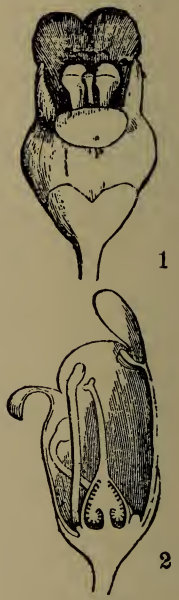


FIG. 200.

FIG. 199.—Actinomorphic flower of Marsh-marigold (Caltha).
FIG. 200.—Zygomorphic flowers of Figwort (Scrophularia). 1. In front view; 2. Side view of a section from back to front.

As to its perianth, the flower is said to be

Dichlamydeous, when both the whorls of the perianth are present;
Monochlamydeous, when but one (usually the calyx) is present;
Apetalous, when the corolla is wanting;
Achlamydeous, or *naked,* when both calyx and corolla are wanting.

As to its stamens and pistils, the flower is

Bisexual or *hermaphrodite*, when stamens and pistils are present;

Unisexual, when, of the essential organs, only the stamens are present (then *staminate*), or only the pistils (then *pistillate*);

Neutral, when both stamens and pistils are wanting.

Collectively, bisexual flowers are said to be *monoclinous;* unisexual flowers, *diclinous;* while in those cases where some flowers are bisexual and others unisexual they are, as a whole, said to be *polygamous.*

Diclinous flowers are further distinguished into

Monœcious, when the staminate and pistillate flowers occur on the same plant, and

Diœcious, when they occur on different plants.

The Perianth, or Floral Envelopes.—In a large number of flowers the parts of the calyx and corolla (sepals and petals) are distinct—i.e., not at all united to one another; such are said to be *chorisepalous* as to the calyx, and *choripetalous* as to the corolla. The terms *polysepalous* and *polypetalous* are the ones most commonly used in English and American books on botany, although they manifestly ought to be used as numerical terms. *Eleutheropetalous* and *dialypetalous* are also somewhat used, especially in German works.

Numerical Terms.—The numerical terms usually employed are *mono-, di-, tri-, tetra-, penta-sepalous*, etc., and *mono-, di-, tri-, tetra-, penta-petalous*, etc., meaning of one, two, three, four, five sepals or petals respectively. *Polysepalous* and *polypetalous* are properly used to designate "a considerable but unspecified number" of sepals or petals.

Union of Parts.—In some flowers the sepals or petals, or both, are united to one another, so that the calyx and corolla are each in the form of a single tube or cup. This union of similar parts is called *coalescence.* The terms *gamosepalous* and *gamopetalous* (or *sympetalous*) are used in such cases. *Monosepalous* and *monopetalous*, still used in this sense in many descriptive works, should be reserved for designating the number of sepals or petals in calyx and corolla respectively.

Adnation.—Not infrequently the calyx and corolla are connately united to each other for a less or greater distance. This union of dissimilar whorls is termed *adnation*, and the calyx and corolla are said to be *adnate* to each other.

In the description of the parts of the perianth their form, size, surface, color, and texture should be observed, using the same terms as are used in case of the leaf.

THE ANDRŒCIUM, OR STAMEN-WHORL.

Numerical Terms.—The number of stamens in the flower or the androecium is indicated by such terms as

Monandrous, signifying of one stamen ;

Diandrous, of two stamens ;

FIG. 201.

FIG. 202.

FIG. 203.

FIG. 201.—Tetrandrous flower ; stamens didynamous.
FIG. 202.—Hexandrous flower ; stamens tetradynamous.
FIG. 203.—Bicyclic androecium.

Triandrous, of three stamens ;

Tetrandrous, of four stamens—when two of the stamens are longer than the other two, the androecium is said to be *didynamous* (Fig. 201) ;

Pentandrous, of five stamens ;

FIG. 204.

FIG. 205.

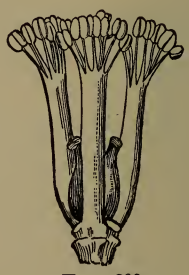


FIG. 206.

FIG. 204.—Androecium of monadelphous stamens.
FIG. 205.—Androecium of diadelphous stamens.
FIG. 206.—Androecium of triadelphous stamens.

Hexandrous, of six stamens ; when four are longer than the remaining two, the androecium is said to be *tetradynamous* (Fig. 202).

Other terms of similar construction are used, as *heptandrous,* seven stamens ; *octandrous,* eight ; *enneandrous,* nine ; *decandrous,* ten ; *dodecandrous,* twelve ; and *polyandrous,* many or an indefinite number of stamens.

The stamens may be in a single whorl (*monocyclic*), in which case, if agreeing in number with the rest of the flower, the androecium is said to be *isostemonous;* they are often in two whorls (*bicyclic*, Fig. 203), and when each whorl agrees with the numerical plan of the flower, the androecium is *diplostemonous.*

Union of Stamens.—The various kinds of union require the use of special terms. When there is a union of the filaments, the androecium is

Monadelphous, when the stamens are united into one set (Fig. 204);

Diadelphous, when united into two sets (Fig. 205);

Triadelphous, when united into three sets, etc. (Fig. 206).

When there is a union of the anthers, the androecium is *syngenesious* or *synantherous.*

Adnation of Stamens.—The stamens may be adnate to the petals, when they are *epipetalous;* in some cases they are adnate to the style of the pistil, as in the Orchids; such are said to be *gynandrous.*

Structure of Stamens.—Each individual stamen is composed of an *anther*, containing one or more pollen-sacs, borne upon a stalk known as the *filament.* (Fig. 207.)

The principal terms which designate the structural relation between the anther and the filament are:

Adnate, applied to anthers which are adherent to the upper or lower surface (anterior or posterior) of the filament; when on the upper surface, the anthers are *introrse;* when on the lower, *extrorse.*

Innate, applied to anthers which are attached laterally to the upper end of the filament, one lobe being on one side, the other on the opposite one. The part of the filament between the two anther-lobes is designated the *connective;* it is subject to many modifications of form, and often becomes separable by a joint at the base of the anther from the rest of the filament.

FIG. 207. Stamen enlarged. *a*, filament; *b*, anther.

Versatile is applied to anthers which are lightly attached to the top of the filament, so as to swing easily; these may also be *introrse* or *extrorse.*

THE GYNŒCIUM.

Numerical Terms.—The gynœcium is made up of one or more *carpels* (*carpids* or *carpophylls*)—i.e., ovule-bearing phyllomes, and it is said to be *mono-*, *di-*, *tri-*, *tetra-*, *penta-*, etc., and *poly-carpellary*, according as it has one, two, three, four, five, to many carpels. In old books the terms *monogynous*, *digynous*, *trigynous*, etc., meaning of one, two, three, etc., carpels, are used instead of the more desirable modern ones. When the carpels are more than one, they may

be distinct, forming the *apocarpous* gynœcium ; or they may be coalescent into one compound organ, the *syncarpous* gynœcium. In the former case the term *pistil* is applied to each carpel, and in the latter to the compound organ. Pistils are thus of two kinds, *simple* and *compound ;* the simple pistil is synonymous with carpel ; the compound pistil with syncarpous gynœcium. (Fig. 208.)

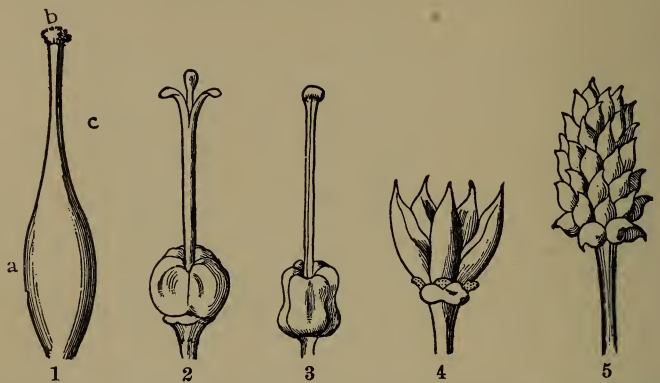


Fig. 208.—Various forms of the gynœcium : 1, monocarpellary; 2, tricarpellary ; 3 and 4, pentacarpellary ; 5, polycarpellary. 4 and 5 are apocarpous; 2 and 3 are syncarpous. In 1 *a* is the ovary ; *c*, the style ; *b*, the stigma.

Simple Pistil.—In the simple pistil the ovules usually grow out from the united margins (the *ventral suture*) of the carpophyll ; the internal ridge or projection upon which they are borne is the *placenta.* Sometimes the ovules are *erect*—i.e., they grow upward from

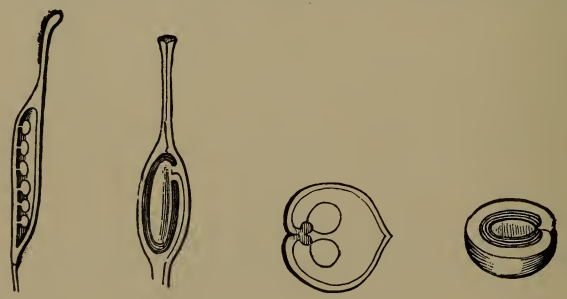


Fig. 209.—Simple pistils. 1 and 2 in longitudinal section ; 3 and 4 in cross-section.

the bottom of the ovary—and when single appear to be direct continuations of the flower-axis. *Suspended* ovules—i.e., those growing from the apex of the ovary-cavity—are also common. (Fig. 209.)

Compound Pistil.—In compound pistils the coalescence may be, on the one hand, of closed carpels, and on the other of open carpels. In the former case the pistil has generally as many *loculi* (cavities or cells) as there are carpels; this is expressed by the terms *bi-*, *tri-*, *quadri-*, and so on to *multi-locular* (5 to 8, Fig. 210). Such pistils have *axile* placentæ—i.e., they are gathered about the axis of the ovary. In the case of compound pistils formed by the coalescence of open carpels the margins only of the latter unite, forming a

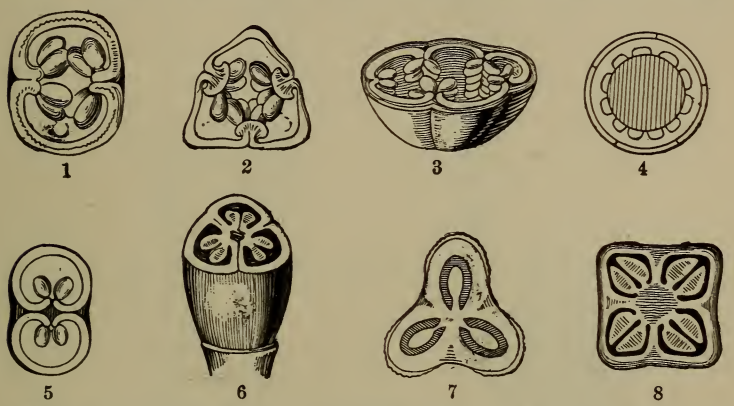


FIG. 210.—Cross-sections of compound pistils: 1, 2, 3, 4, unilocular; 5, bilocular; 6 and 7, trilocular; 8, quadrilocular. 1, 2, 3, with parietal placentæ; 4, with a free central placenta; 5 to 8, with axile placentæ.

common ovary-cavity (*unilocular*, 1, 2, 3, Fig. 210); here the placentæ generally occur along the sutures, and are said to be *parietal*—i.e., on the walls. Between such unilocular pistils and the multilocular ones described above there are all intermediate gradations. In one series of gradations the placentæ project farther and farther into the ovary-cavity, at last meeting in the centre, when the pistil becomes multilocular with axile placentæ. On the other hand, a multilocular pistil sometimes becomes unilocular by the breaking away of the partitions during growth. In such a case the placentæ form a free central column, commonly called a *free central palcenta* (4, Fig. 210). In other cases a free central placenta from the first occupies the axis of a unilocular but evidently ploycarpellary pistil. In Anagallis, for example, the placental column grows from the base of the ovary-cavity, and there is at no time a trace of partitions. Here we may say that the partitions are suppressed.

Adnation of the Gynœcium.—The gynœcium may be free from all the other organs of the flower, which are then said to be *hypogyn-*

ous, and the gynœcium itself *superior* (Fig. 211). Sometimes the growth of the broad flower-axis stops at its apex long before it does so in its marginal portions; a tubular ring is thus formed, carrying up calyx, corolla, and stamens, which are then said to be *perigynous*, and the gynœcium *half inferior*. These terms are used also in the cases where the gynœcium is similarly surrounded by the tubular sheath composed of adnate calyx, corolla, and andrœcium. In some nearly related cases, in addition to the structures described above as perigynous, there is a complete fusion of the calyx, corolla, and

FIG. 211.

FIG, 212.

FIG. 211.—Flower of Shepherd's-purse (Bursa), with superior ovary, and hypogynous stamens and perianth.

FIG. 212.—Flower of Watermelon, with inferior ovary, and epigynous perianth.

stamen-bearing tube with the gynœcium, so that the ovule-bearing portion of the latter is below the rest of the flower. The perianth and the stamens are said to be *epigynous* in such flowers, and the ovary is *inferior*. (Fig. 212.) Some cases of epigyny are doubtless to be regarded as due to the adnation of the calyx, corolla, stamens, and ovaries; in others the ovaries are adnate to the hollow axis which bears the perianth and stamens.

Certain terms descriptive of relations between the stamens and pistils which have recently come into use require explanation here.

Relative Terms.—In many flowers the stamens and pistils do not mature at the same time—such are said to be *dichogamous;* when the stamens mature before, the pistils the flower is *proterandrous;* and when the pistils mature before the stamens they are *proterogynous.*

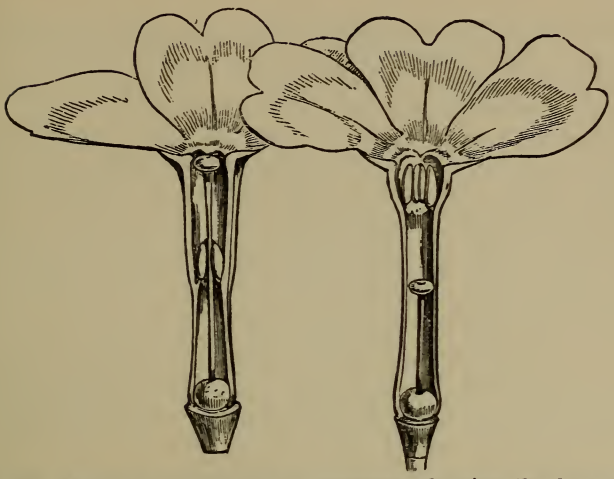


FIG. 213.—Heterostyled flowers of Primrose, showing the long-styled form in the left-hand figure, and the short-styled form in the figure on the right. (From Darwin.)

FIG. 214.—Heterostyled flowers of Buckwheat; the upper figure showing the long-styled form, the lower the short-styled. (From Müller.)

In some species of plants there are two or three kinds of flowers, differing as to the relative lengths of the stamens and styles; these are called *heterogonous* or *heterostyled*. When there are two forms,

viz., one in which the stamens are long and the styles short, and the other with short stamens and long styles, the flowers are said to be *dimorphous*, or, more accurately, *heterogonous dimorphous*, and the forms are distinguished as *short-styled* and *long-styled*.

Examples of dimorphous flowers are common in many genera of plants; e.g., in Bluets (Houstonia), Partridge berry (Mitchella), Primrose (Primula), Puccoon (Lithospermum), Buckwheat (Fagopyrum), etc., etc. (Figs. 213 and 214).

When, as in some species of Oxalis, there are three forms, viz., long-, mid-, and short-styled, the term *trimorphous* (or, better, *heterogonous trimorphous*) is used (Fig. 215).

§ 6. The Fruit.

Structure.—The fruit may include (1) only the ripened ovary (pericarp) with its contained seeds—e.g., the bean; or (2) these with an adnate calyx or receptacle—e.g., the apple.

Fig. 215.—Long-, mid-, and short-styled flowers of Oxalis speciosa, after the removal of the floral envelopes. (From Darwin.)

During the ripening changes in structure may take place, as (1) the growth of wings or prickles; (2) the thickening of the walls and the formation of a soft and juicy pulp; (3) the hardening of some portions of the ovary-wall by the development of stony tissue; (4) the thickening and growth of the adnate calyx or receptacle, etc., etc.

Where the ripening walls remain thin and become dry, the fruits are said to be *dry*, e.g., in the bean; where they become thickened and more or less pulpy, they are *fleshy*, e.g., the peach. These terms are used also when the fruit includes an adnate calyx or receptacle.

In many fleshy fruits (developed from carpels) the inner part of the pericarp-wall is hardened; the two layers are then distinguished as *exocarp* and *endocarp;* when there are three layers, the middle one is the *mesocarp*.

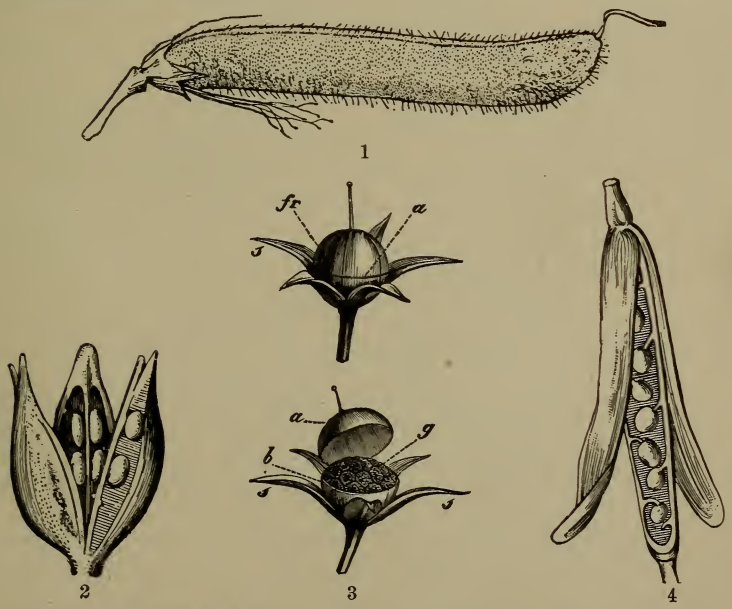
Dehiscence.—The opening of the fruit in order to permit the escape of the seeds is called its *dehiscence,* and such fruits are said to be *dehiscent;* those which do not open are *indehiscent.* In fruits developed from single carpels dehiscence is generally through the ventral or dorsal suture, or both ; in those developed from compound pistils the partitions may split, and thus resolve each fruit into its original carpels (*septicidal dehiscence*) ; or the dorsal sutures may become vertically ruptured, thus opening every cell (loculus) by a vertical slit (*loculicidal dehiscence,* Fig. 226, 2). Among the other forms of dehiscence only that called *circumscissile,* Fig. 216, 3, and the *irregular* need be mentioned ; in the former a transverse slit separates a lid or cap, exposing the seeds ; in the latter one or more irregular slits form, and through these the seeds escape.

Kinds of Fruits.—The principal fruits may be distinguished by the brief characters given in the following table :

A. MONOGYNŒCIAL FRUITS.

formed by the gynœcium of one flower.

I. **Capsulary Fruits.—The Capsules.**—Dry, dehiscent, formed from one pistil (Fig. 216).



1 2 3 4

FIG. 216.—Capsulary fruits: 1, legume: 2, capsule, showing loculicidal dehiscence; 3, pyxis, showing circumscissile dehiscence ; 4, silique.

1. Monocarpellary.
   (*a*) Opening by one suture—e.g., Caltha.....FOLLICLE.
   (*b*) Opening by both sutures—e.g., Pea.....LEGUME.
2. Bi- to polycarpellary—e.g., Viola.....CAPSULE.
   Var. *a*. Dehiscence circumscissile—e.g., Anagallis.....Pyxis.
   Var. *b*. Dehiscence by the falling away of two lateral valves from the two persistent parietal placentæ—e.g., Mustard.....Silique.

II. **Schizocarpic Fruits.—The Splitting Fruits.**—Dry, breaking up into one-celled indehiscent portions (Fig. 217).

FIG. 217.—Splitting Fruit (cremocarp) of Fennel, showing the slender branching receptacle (carpophore) which supports the two halves (mericarps).

1. Monocarpellary, dividing transversely—e.g., Desmodium.....LOMENT.
2. Bi-to polycarpellary.
   (*a*) Dividing into achene-like or nut-like parts (*nutlets*), no forked carpophore—e.g., Lithospermum.....CARCERULUS.
   (*b*) Dividing into two achene-like parts (*mericarps*), a forked carpophore between them—e.g., Umbelliferæ.....CREMOCARP.

III. **Achenial Fruits.—The Achenes.**—Dry, indehiscent, one-celled, one or few seeded, not breaking up (Fig. 218).

1. Pericarp hard and thick—e.g., Oak.....NUT.
2. Pericarp thin—e.g., Buckwheat.....ACHENE.
   Var. *a*. Pericarp loose and bladder-like—e.g., Chenopodium.....Utricle.
   Var. *b*. Pericarp consolidated with the seed—e. g., Grasses.....Caryopsis.
   Var. *c*. Pericarp prolonged into a wing—e.g., Ash.....Samara.

IV. **Baccate Fruits.—The Berries.**—Fleshy, indehiscent; seed in pulp (Fig. 219).

1. Rind firm and hard—e.g., Pumpkin.....PEPO.
2. Rind thin—e.g., Grape.....BERRY.

V. **Drupaceous Fruits.—The Drupes.**—Fleshy, indehiscent; endocarp hardened, usually stony.

1. One stone, usually one-celled—e.g., Cherry.....DRUPE.
2. Stones or papery carpels, two or more—
   e.g., Apple.....POME.

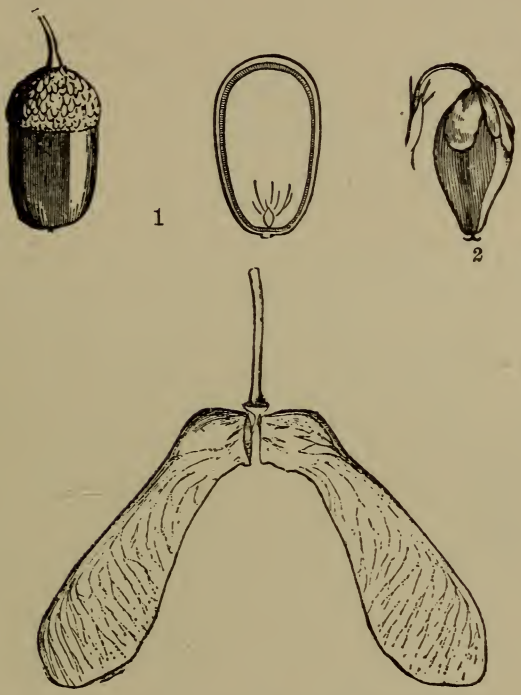


FIG. 218.—Achenial Fruits: 1, nut of Oak, also shown in section; 2, achene of Buckwheat; 3, double samara of Maple.

VI. **Aggregate Fruits.**—Polycarpellary; carpels always distinct. The forms of these are not well distinguished. In many Ranunculaceæ there are numerous achenes on a prolonged receptacle; in Magnolia numerous follicles are similarly arranged; in the raspberry many drupelets cohere slightly into a loose mass, which separates at maturity from the dry receptacle; in the blackberry similar drupelets remain closely attached to the fleshy receptacle; in the strawberry there are many small achenes on the surface of the fleshy receptacle; finally, in the rose several to many achenes are enclosed within the hollow and somewhat fleshy receptacle.

FIG. 219.
Berry of Grape

B. POLYGYNŒCIAL FRUITS.

formed by the gynœcia of several flowers.

1. A spike with fleshy bracts and perianths—e.g., Mulberry.....Sorosis
2. A spike with dry bracts and perianths—e.g., Birch.....Strobile.
3. A concave or hollow, fleshy receptacle, enclosing many dry gynœcia—e.g., Fig.....Syconus.

§ 7. The Seed.

The seed is the ripened ovule, and as the ovule consists of a *body*, surrounded by one or two *coats* or *integuments*, we may look for a like structure in the seed. However, the modifications which most seeds undergo render necessary some additional terms. Thus the outer integument is generally so thickened and hardened that it is commonly called the *testa*. The inner is sometimes called the *tegmen*. In some seeds the outer coat becomes fleshy, in which case they are *baccate* (berry-like); in others the outer part of the testa is fleshy and the inner hardened, so that the seed is *drupaceous* (drupe-like). Occasionally an additional coat forms around the ovule after fertilization; it differs somewhat in nature in different plants, but all are commonly included under the name *aril*—e.g., in May-apple.

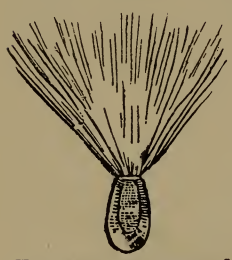


Fig. 220.—Comose seed of Milkweed.

The testa may be prolonged into one or more flat extensions; such a seed is *winged*—e.g., Catalpa. Its epidermal cells may be prolonged into trichomes, forming the *comose* seed—e.g., milkweed (Fig. 220).

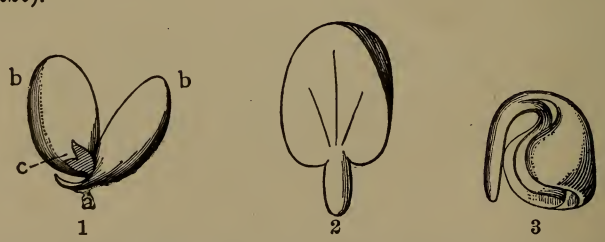


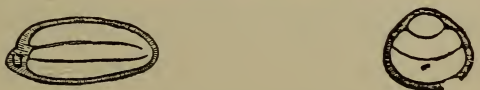
Fig. 221.—Embryos dissected out from seeds: 1, showing at *a* the "radicle;" *b*, *b*, the first leaves (cotyledons); *c*, the third and fourth leaves (plumule). 2, a straight embryo. 3, embryo folded upon itself (incumbent).

The embryo occupies either the whole of the seed-cavity, in *exalbuminous* seeds (Figs. 223 and 224), or it lies in or in contact with

1 2 3

FIG. 222.—Albuminous (endospermous) seeds: 1, of Moonseed, 2, of Chenopodium, each with a curved embryo; 3, of Marsh-marigold (Caltha) with minute straight embryo.

the endosperm, in the *albuminous* seeds (Fig. 222). It is *straight*—e.g., the pumpkin; or variously curved and folded—e.g., in Erysimum, where the cotyledons are *incumbent*, i.e., with the little stem folded up against the back of one of the cotyledons, and in Arabis (Fig. 223), where they are *accumbent*, i.e., with the little stem folded up so as to touch the edges of the cotyledons (Fig. 224).



1 2

FIG. 223.—Incumbent cotyledons of Erysimum: 1, longitudinal section of seed; 2, cross-section of seed.

1 2

FIG. 224.—Accumbent cotyledons of Arabis: 1, longitudinal section of seed; 2, cross-section of seed.

CHAPTER XIV.

THE SYSTEMATIC ARRANGEMENT OF THE ANGIOSPERMS.

547. Many attempts have been made to arrange the vast number of species of Angiosperms in a logical system, but none of them have proved to be quite satisfactory. For a long time the Candollean system, and later its modification by Bentham and Hooker, have been followed in most botanical publications, but within a few years the system of Engler and Prantl has been favorably received by many botanists.

548. The sequence adopted in this chapter differs somewhat from either system mentioned, and is based upon the proposition that in the primitive flower all the parts were separate. The first flowers on the earth, in the Permian or Triassic period, must have been apocarpous, that is, with their pistils simple and separate. Their stamens must, likewise, have been separate from one another and from other organs. So too their floral leaves (perianth) must have been of separate phyllomes. This is the structure of the typical Apocarpæ, the lower Thalamifloræ, and the lower Calycifloræ, which are accordingly placed at the beginning of the system.

549. The earliest modification of this primitive structure was probably the union of the carpels into a compound pistil, as in the Coronarieæ and many families of the

Thalamifloræ. From this general type evolution appears to have been by two methods, viz., (1) a simplification of the floral structure by the decrease of floral leaves, stamens, carpels, and ovules, as in Aroids, Palms, Sedges, and Grasses in the Monocotyledons, and the many apetalous families of the Dicotyledons, and (2) an increase in the complexity of structure of the floral leaves, their union with one another, and the adaptation of the whole flower to insect agency in pollination, culminating in the upgrowth of the stamens and floral leaves around and above the ovary, so that the latter is inferior in the mature flower.

550. Accordingly we must regard a gamopetalous flower whose structure is otherwise similar as higher than one with separate petals. So too the flower whose ovary is inferior is higher than one of like structure having a superior ovary. It follows that a flower with an inferior ovary and also a gamopetalous corolla must be held as highest in structure.

551. It is here assumed that the apocarpous Ranales and Rosales represent the primitive Dicotyledonous types, and that from these, syncarpy was quickly reached along two divergent genetic lines, viz., the Thalamifloral and the Calycifloral. From the former gamopetaly was attained (from that fruitful sub-order the Caryophyllales), resulting in the Primulales, Polemoniales, and related sub-orders in the Heteromeræ and Bicarpellatæ. Epigyny was not reached in this genetic line, except in a few aberrant families. In the Calycifloræ the evolution of the flower quickly reached epigyny, this being accomplished long before the appearance of gamopetaly (in the Inferæ), but here again in certain aberrant families gamopetaly was temporarily attained in the Calycifloræ.

552. The general relations of the orders and sub-orders of the Angiosperms as here understood may be indicated by the accompanying diagram (Fig. 225).

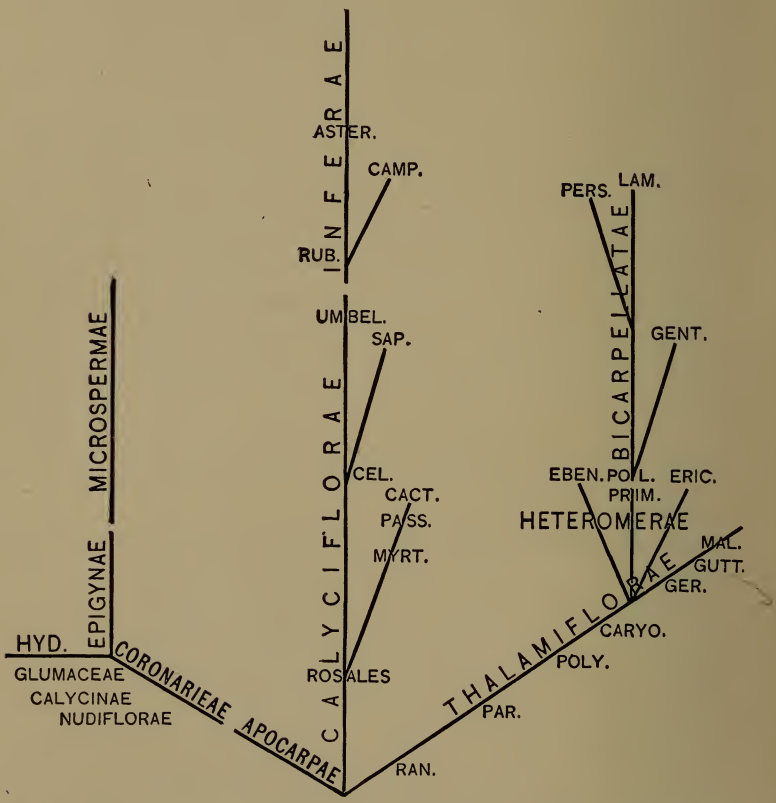


FIG. 225.—Diagram to illustrate the relationship of the orders and sub-orders of the Angiosperms.

CLASS 15. ANGIOSPERMÆ. THE ANGIOSPERMS.

Spore-bearing leaves (carpels) of the sporophore folded so as to enclose the ovules in a cavity, thus constituting a pistil; seeds enclosed. Species about 100,000.

Sub-class 1. **Monocotyledoneæ.** The Monocotyledons.

Leaves of young sporophore alternate; leaves of mature sporophore usually parallel-veined; fibro-vascular bundles of the stem scattered, usually not arranged in rings.

Order 39. **APOCARPÆ.** Water-plantains.

Pistils separate, superior to all other parts of the flower.

Family **Alismaceæ** (Water-plantains): Aquatic or paludose herbs with mostly radical, often large leaves; flowers small to large; perianth in two whorls of three leaves each (calyx and corolla). (Species 55.)

Family **Triurideæ**: Very small, pale, leafless plants growing in wet places in tropical countries. (Sp. 16.)

Family **Naiadaceæ** (Pondweeds): Aquatic or paludose herbs with mostly alternate stem-leaves; flowers mostly small and inconspicuous; perianth none or of one to six leaves in one or two whorls. (Sp. 120.)

Order 40. **CORONARIEÆ.** Lilies.

Pistils united (usually 3), forming a compound pistil, superior; flower-leaves (usually 6, in two whorls) delicate and corolla-like.

Family **Stemonaceæ**: Pistil 1-celled; stamens 4; perianth of two similar whorls, each of two similar leaves. (Sp. 7.)

Family **Liliaceæ** (The Lilies): Pistil mostly 3-celled; stamens 6; perianth of two similar whorls, each of three similar leaves. (Sp. 2300.)

Family **Pontederiaceæ** (Pickerel-weeds): Aquatic herbs with 3- or 1-celled pistil; stamens 6 or 3; perianth of two similar whorls, each of three similar or dissimilar leaves. (Sp. 34.)

Family **Phylidraceæ**: Pistil 3-celled; stamen 1; perianth of two similar whorls, each of two dissimilar leaves. (Sp. 3.)

Family **Xyridaceæ** (Yellow-eyed Grasses): Rush-like plants with a 1-celled or incompletely 3-celled pistil; stamens 3; perianth of two dissimilar whorls each of three similar leaves. (Sp. 47)

Family **Mayaceæ**: Slender, creeping, moss-like plants with 1-celled pistil; stamens 3; perianth of two dissimilar whorls, each of three similar leaves. (Sp. 7.)

Family **Commelinaceæ** (Spiderworts): Succulent herbs with 3- or 2-celled pistil; stamens 6; perianth of two dissimilar whorls of three similar leaves. (Sp. 700.)

Family **Rapateaceæ**: Tall, sedge-like marsh herbs with 3-celled pistil; stamens 6, in pairs; perianth of two dissimilar whorls, each of three similar leaves. (Sp. 21.)

Order 41. NUDIFLORÆ. Aroids.

Compound pistil mostly tricarpellary, superior; ovules more than one; flower-leaves reduced to scales or entirely wanting.

Family **Pandanaceæ** (Screw-pines): Shrubs or trees with spirally crowded, narrow, stiff leaves on the ends of the branches; pistil 1-celled; ovules one or many. (Sp. 83.)

Family **Cyclanthaceæ**: Mostly herbaceous plants with broad petioled leaves having parallel venation; pistil 1-celled; ovules many, on four parietal placentæ. (Sp. 44.)

Family **Typhaceæ** (Cat-tails): Aquatic or paludose herbs with linear sheathing leaves; pistil 1-celled; ovule 1. (Sp. 16.)

Family **Aroideæ** (The Aroids): Mostly herbaceous plants with broad petioled leaves, having reticulate venation; pistil 1- to 4-celled; ovules 1 or more. (Sp. 900.)

Family **Lemnaceæ** (Duckweeds): Very small floating aquatic herbs; pistil 1-celled; ovules 1 or more. (Sp. 19.)

Order 42. CALYCINÆ. Palms.

Compound pistil mostly tricarpellary, superior; ovules usually one; flower-leaves reduced to rigid or herbaceous scales.

Family **Flagellarieæ**: Erect or climbing herbs with long narrow leaves; pistil 3 celled; ovules solitary; fruit a 1- to 2-seeded berry. (Sp. 6.)

Family **Juncaceæ** (The Rushes): Herbs with narrow leaves; pistil 1- to 3-celled; ovules solitary or many; fruit a dry 3-valved pod. (Sp. 210.)

Family **Palmaceæ** (The Palms): Trees or shrubs with compound leaves; pistil 1- to 3-celled; fruit a 1-seeded berry or drupe (rarely 2- to 3-seeded). (Sp. 1100.)

Order 43. GLUMACEÆ. Grasses.

Compound pistil reduced to 1 or 2 carpels (rarely tricarpellary); ovule solitary; flower-leaves reduced to small scales or entirely wanting.

Family **Eriocauleæ**: Rush-like herbs with flowers in close heads; perianth segments 6 or less, small; pistil 3- or 2-celled; ovules orthotropous, pendulous. (Sp. 338.)

Family **Centrolepideæ**: Small rush-like herbs with flowers in spikes or heads ; perianth none ; pistil 1- to 3-celled ; ovules orthotropous, pendulous. (Sp. 32.)

Family **Restiaceæ**: Rush-like herbs or undershrubs with spiked, racemed, or panicled flowers ; perianth segments 6 or less, chaffy ; pistil 1- to 3-celled ; ovules orthotropous, pendulous. (Sp. 240.)

Family **Cyperaceæ** (The Sedges) : Grass-like herbs with 3-ranked leaves ; perianth segments bristly or none ; pistil 1-celled ; ovules anatropous, erect. (Sp. 2200.)

Family **Gramineæ** (The Grasses) : Mostly erect herbs with hollow jointed stems and 2-ranked leaves ; perianth segments of 2 to 6 thin scales or none ; pistil 1-celled ; ovules anatropous, ascending. (Sp 3500.)

Order 44. **HYDRALES.** Waterworts.

Compound tricarpellary pistil, inferior to all other parts of the flower ; flower-leaves in each whorl alike in shape (flower regular) ; seeds without endosperm.

Family **Hydrocharideæ** (Waterworts) : Small aquatic herbs mostly inhabiting the fresh waters of temperate climates. (Sp. 40.)

Order 45. **EPIGYNÆ.** Irids.

Compound tricarpellary pistil, inferior ; flower-leaves in each whorl mostly alike in shape (flower regular) ; seeds with endosperm.

Family **Dioscoreaceæ** (Yams) : Mostly twining herbs with broad, petioled, longitudinally veined leaves ; pistil 3 celled ; ovules 2 in each cell ; stamens 6. (Sp. 170.)

Family **Taccaceæ** : Stemless herbs with broad pinnately parallel veined leaves ; pistil 1-celled ; ovules many ; stamens 6. (Sp. 10.)

Family **Amaryllidaceæ** (The Amaryllids) : Leaves narrow, or the blade broad with longitudinal veins ; pistil 3 celled ; ovules many ; stamens 6 or 3. (Sp. 650.)

Family **Iridaceæ** (The Irises) : Leaves sword-shaped ; pistil 3-celled ; ovules many ; stamens 3. (Sp. 770.)

Family **Hæmodoraceæ** (Bloodworts) : Leaves sword-shaped ; pistil 3-celled ; ovules 1 to many ; stamens 6. (Sp. 125.)

Family **Bromeliaceæ** (Pineapples) : Leaves mostly rosulate ; external perianth whorl calycine ; pistil 3-celled ; ovules many ; stamens 6. (Sp. 525.)

Family **Scitamineæ** (Bananas) : Leaves mostly ample, pinnately parallel veined ; external perianth whorl calycine ; pistil 3-celled or becoming 1-celled ; stamens mostly 1 (rarely 5). (Sp. 520.)

Order 46. **MICROSPERMÆ.** Orchids.

Compound tricarpellary pistil, inferior; flower-leaves in each whorl mostly unlike in shape (flower irregular); seeds without endosperm.

Family **Burmanniaceæ**: Flowers regular; stamens 3 or 6. (Sp. 50.)

Family **Orchidaceæ** (The Orchids): Flowers irregular; stamens 1 or 2. (Sp. 5000.)

Sub-class 2. **Dicotyledoneæ.** The Dicotyledons.

Leaves of young sporophore opposite; leaves of mature sporophore usually reticulate-veined; fibro-vascular bundles of the stems in one or more rings.

The Dicotyledons were formerly divided into Choripetalæ, Gamopetalæ and Apetalæ, but these artificial groups should no longer be maintained.

Order 47. **THALAMIFLORÆ.** Torals.

Outer whorl (calyx) usually of separate leaves (sepals), and with the other parts of the flower inserted on the flower-axis (torus).

Sub order Ranales: Pistils 1 to many, monocarpellary (or rarely united); stamens generally indefinite; embryo mostly small in copious endosperm.

Family **Ranunculaceæ** (The Crowfoots): Petals present, in one whorl or absent; sepals deciduous; mostly herbs with alternate leaves. (Sp. 680.)

Family **Dilleniacèæ**: Petals present, in one whorl; sepals persistent; mostly shrubs and trees with alternate leaves. (Sp. 200.)

Family **Calycanthaceæ**: Petals present, in many whorls; seeds without endosperm; shrubs with opposite leaves. (Sp. 5.)

Family **Magnoliaceæ** (Magnolias): Petals present, in one to many whorls; receptacle usually elongated; shrubs and trees with alternate leaves and usually large flowers. (Sp. 86.)

Family **Anonaceæ** (Anonads): Petals present, in two whorls of 3 each; endosperm ruminated; trees or shrubs with alternate leaves. (Sp. 450)

Family **Myristicaceæ** (The Nutmegs): Petals absent; pistil 1 (or a second rudiment), 1-seeded; endosperm ruminated; trees or shrubs with alternate leaves and small, inconspicuous, dicœcious flowers. (Sp. 90.)

Family **Monimiaceæ**: Petals absent; pistils many, 1-ovuled, imbedded in the receptacle; trees and shrubs with opposite or whorled leaves and diclinous flowers. (Sp. 150.)

Family **Chloranthaceæ**: No perianth whatever; pistil 1 with 1 ovule; mostly trees and shrubs with opposite leaves and small flowers. (Sp. 34.)

Family **Menispermaceæ** (Moonseeds): Petals present, in 2 whorls; twining shrubs with alternate leaves and small diclinous flowers. (Sp. 255.)

Family **Berberidaceæ** (Barberries): Petals usually present, in 1 to 3 whorls; pistil 1 (rarely more) with many ovules; mostly shrubs with alternate leaves and perfect flowers. (Sp. 105.)

Family **Nymphæaceæ** (Water-lilies): Petals present, in 1 to many whorls; pistils several or united; aquatic herbs with floating leaves. (Sp. 35.)

Sub-order Parietales: Pistil of 2 or more united carpels, mostly 1-celled with parietal placentæ; stamens indefinite or definite; endosperm none or copious.

Family **Sarraceniaceæ** (Pitcher-plants): Herbs with pitcher-shaped leaves; sepals 4–5; petals 5–0; stamens indefinite; pistil 3–5-carpellary. (Sp. 10.)

Family **Papaveraceæ** (Poppies): Mostly milky-juiced plants with alternate leaves; sepals 2–3; petals 4 or more (or 0); stamens indefinite; pistil many-carpellary. (Sp. 210.)

Family **Cruciferæ** (Crucifers): Herbs, rarely shrubs, with alternate (or opposite) leaves; sepals 4; petals 4; stamens 6 or 4; pistil 2-carpellary. (Sp. 1550.)

Family **Capparidaceæ** (Capparids): Herbs, shrubs, and trees with alternate or opposite leaves; sepals 4; petals 4 (or 0); stamens 4 (or many); pistil 2- to 6-carpellary. (Sp. 355.)

Family **Resedaceæ** (Mignonettes): Herbs and shrubs with scattered leaves; sepals 4–8; petals 4–8 (or 2 or 0); stamens 3–40; pistil 2- to 6-carpellary. (Sp. 45).

Family **Cistaceæ** (Rock-roses): Herbs and shrubs with opposite (or alternate) leaves; sepals 3–5; petals 5; stamens many; pistil 3- to 5-carpellary. (Sp. 71.)

Family **Violaceæ** (Violets): Herbs and shrubs with alternate (or opposite) leaves; sepals and petals 5, irregular; stamens 5; pistil 3-carpellary. (Sp. 270.)

Family **Canellaceæ**: Aromatic trees with alternate leaves; sepals 4–5; petals 4–5 (or 0); stamens 20–30; pistil 2- to 5-carpellary. (Sp. 6.)

Family **Bixaceæ**: Shrubs and trees with alternate leaves; sepals 3 to 7; petals various (or 0); stamens indefinite; pistil 2- to many-carpellary. (Sp. 180.)

Family **Samydaceæ**: Trees and shrubs with alternate leaves; sepals 3–7; petals 3–7 (or 0); stamens definite or indefinite: pistils 3–5-carpellary. (Sp. 160.)

Family **Lacistemaceæ**: Shrubs and trees with alternate leaves; perianth 0; stamen 1; pistil 3- or 2-carpellary. (Sp. 16.)

Family **Nepenthaceæ** (Pitcher-leaves): Undershrubs with pitcher-shaped leaves; sepals 4 or 3; petals 0; stamens 4–16; pistil 4- to 3-carpellary. (Sp. 31.)

SUB-ORDER POLYGALALES: Pistil mostly of two united carpels, 2-celled; stamens as many or twice as many as the petals; seed endospermous.

Family **Pittosporaceæ**: Trees and shrubs with alternate leaves; sepals, petals, and stamens 5 each. (Sp. 90.)

Family **Tremandraceæ**: Small shrubs with alternate, opposite, or whorled leaves; sepals and petals 3, 4, or 5 each; stamens twice as many. (Sp. 27.)

Family **Polygalaceæ** (Milkworts): Herbs, shrubs, and trees with alternate leaves; sepals 5; petals 3–5; stamens usually 8. (Sp. 470.)

Family **Vochysiaceæ**: Shrubs and trees with opposite or whorled leaves; sepals 5; petals 1, 3, or 5; stamens several, usually but one fertile. (Sp. 130.)

SUB-ORDER CARYOPHYLLALES: Pistil usually of 3 or more united carpels, mostly 1-celled, with a free central placenta and many ovules (sometimes reduced to a one-celled, one-ovuled ovary); stamens as many or twice as many as the petals; seeds endospermous, usually with a curved embryo.

Family **Frankeniaceæ**: Herbs and undershrubs with opposite leaves; petals 4–5, long-stalked; ovules many on 2–4 parietal placentæ. (Sp. 32.)

Family **Caryophyllaceæ** (The Pinks): Herbs (and shrubs) with opposite leaves; petals 3–5, stalked or not; ovules many on a central placenta. (Sp. 1100.)

Family **Tamariscaceæ** (Tamarisks): Shrubs and herbs with minute alternate leaves; petals 5; ovules many on central or parietal placentæ. (Sp. 45.)

Family **Salicaceæ** (The Willows): Shrubs and trees with alternate leaves; perianth 0; ovules many on 2–4 parietal placentæ. (Sp. 178.)

Family **Ficoideæ**: Herbs and shrubs with alternate, opposite, or whorled leaves; petals indefinite or 0; seeds many on parietal placentæ, or 1 and erect. (Sp. 590.)

Family **Nyctaginaceæ** (Four-o'clocks): Herbs and shrubs with opposite leaves; petals 0; sepals petaloid; ovule 1, erect. (Sp. 120.)

Family **Illecebraceæ**: Herbs (and shrubs) with opposite leaves; petals scale-like or 0; ovule 1, erect or pendulous. (Sp. 90.)

Family **Amaranthaceæ** (Amaranths): Herbs, shrubs (and trees)

with opposite leaves; petals 0; ovules 1 or more, basal, campylotropous. (Sp. 450.)

Family **Chenopodiaceæ** (Chenopods): Herbs, shrubs (and trees) with mostly alternate leaves; petals 0; ovule 1, basal, campylotropous. (Sp. 520.)

Family **Phytolaccaceæ** (Pokeweeds): Herbs, shrubs, and trees with usually alternate leaves; petals 0 (or 4–5); carpels several, distinct or nearly so, 1-ovuled. (Sp. 55.)

Family **Batideæ**: Shrub with opposite leaves; petals 0; ovary 4-celled; ovule solitary, erect. (Sp. 1.)

Family **Polygonaceæ** (Buckwheats): Herbs, shrubs, and trees with alternate leaves; petals 0; ovule 1, erect, orthotropous. (Sp. 750.)

SUB-ORDER GERANIALES: Receptacle usually with an annular or glandular disk; pistil of several carpels; ovules 1 to 2 (or many), mostly pendulous.

Family **Linaceæ** (Flaxworts): Herbs and shrubs with alternate simple leaves; pistil 3- to 5-celled; endosperm fleshy or 0. (Sp. 235.)

Family **Humiriaceæ**: Trees with alternate simple leaves; pistil 5- to 7-celled; endosperm copious. (Sp. 32.)

Family **Malpighiaceæ**: Trees and shrubs with usually opposite, simple or lobed leaves; pistil tricarpellary; endosperm 0. (Sp. 600.)

Family **Zygophyllaceæ**: Herbs and shrubs with usually opposite compound leaves; pistil lobed, 4- to 5-celled; endosperm copious or 0. (Sp. 110.)

Family **Geraniaceæ** (Geraniums): Herbs, shrubs, and trees with opposite or alternate (compound or simple) leaves; torus elongated; pistil lobed, 3- to 5-celled; endosperm sparse or 0. (Sp. 986.)

Family **Rutaceæ** (Rueworts): Herbs, shrubs, and trees with glandular-dotted, opposite, simple, or compound leaves; pistil lobed, 4- to 5-celled; endosperm fleshy or 0. (Sp. 782.)

Family **Simarubaceæ** (Quassiads): Trees and shrubs with generally alternate, non-glandular, simple, or compound leaves; pistil lobed, 1- to 5-celled; endosperm fleshy or 0. (Sp. 110.)

Family **Ochnaceæ**: Shrubs and trees with alternate, coriaceous, simple leaves; pistil lobed, 1- to 10-celled; endosperm fleshy or 0. (Sp. 160.)

Family **Burseraceæ**: Balsamic trees and shrubs with alternate compound leaves; pistil 2- to 5-celled; endosperm 0. (Sp. 275.)

Family **Meliaceæ** (Miliads): Trees and shrubs with alternate compound leaves; pistil 3- to 5-celled; endosperm present or 0. (Sp. 550.)

Family **Dichapetaleæ**: Trees and shrubs with alternate simple leaves; pistil 2- to 3-celled; endosperm 0. (Sp. 54.)

Sub-order Guttiferales: Pistil mostly of 2 or more carpels, 2-celled, with axile placentæ; stamens usually indefinite; endosperm usually wanting.

Family **Elatineæ**: Small marsh herbs or undershrubs with small opposite or whorled leaves; inflorescence axillary; petals imbricated; stamens 4–10. (Sp. 25.)

Family **Hypericaceæ** (St. John's-worts): Herbs, shrubs (and trees) with opposite or whorled, glandular-dotted leaves; inflorescence dichotomous or paniculate; petals contorted or imbricated; stamens in 3–5 clusters. (Sp. 240.)

Family **Guttiferæ** (Guttifers): Trees and shrubs with opposite or whorled leaves; inflorescence often trichotomous; petals imbricated or contorted. (Sp. 370)

Family **Ternstrœmiaceæ** (Theads): Trees and shrubs usually with alternate leaves; inflorescence various; petals imbricated. (Sp. 310.)

Family **Dipterocarpeæ**: Trees and shrubs with alternate leaves; inflorescence panicled; petals contorted; fruiting calyx enlarged in fruit. (Sp. 182.)

Family **Chlænaceæ**: Trees and shrubs with alternate leaves; inflorescence dichotomous; petals contorted. (Sp. 14.)

Sub-order Malvales: Pistil usually of 3 to many carpels with as many cells (sometimes greatly reduced); ovules few; stamens indefinite, monadelphous, branched, or by reduction separate and few; endosperm present or absent.

Family **Malvaceæ** (Mallows): Herbs, shrubs, and trees with alternate leaves; flowers perfect, with petals; stamens monadelphous, 1-celled; pistil 5- to many-celled; endosperm little or 0. (Sp. 800.)

Family **Sterculiaceæ**: Trees and shrubs with alternate leaves; flowers perfect or diclinous, with or without petals; stamens mon- or polyadelphous, 2-celled; pistil 4- to many-celled; endosperm present or 0. (Sp. 730.)

Family **Tiliaceæ** (Lindens): Trees, shrubs (and herbs) with mostly alternate leaves; flowers mostly perfect, with petals; stamens free, 2-celled; pistil 2- to 10-celled; endosperm present or 0. (Sp. 470.)

Family **Euphorbiaceæ** (Spurgeworts): Herbs, shrubs, and trees, mostly with a milky juice and alternate or opposite leaves; flowers diclinous, with a perianth of 1 or 2 whorls, or wanting; stamens 2-celled, free or united; pistil usually 3-celled; endosperm copious. (Sp. 3000.)

Family **Balanopseæ**: Trees and shrubs with alternate leaves; flowers dicœcious, apetalous, the staminate in catkins, the pistillate solitary, producing acorn-like, 2-celled, 2-seeded fruits; seeds endospermous. (Sp. 8.)

Family **Empetraceæ** (Crowberries): Heath-like shrubs with small leaves; flowers small, mostly dicœcious, solitary or in heads; petals present; stamens 2 to 3, 2- to 3-celled; pistil 2- to many-celled; seeds solitary, endospermous. (Sp. 4.)

Family **Urticaceæ** (Nettleworts): Herbs, shrubs, and trees with alternate or opposite leaves; flowers mostly diclinous, without petals; stamens few, 2-celled; pistil monocarpellary, 1-celled, mostly 1-seeded; endosperm none. (Sp. 1560.)

Family **Platanaceæ** (Plane trees): Trees with alternate leaves and monœcious flowers in globular heads; perianth 0; pistils 1-celled, 1-ovuled; endosperm minute. (Sp. 6.)

Family **Leitneriaceæ**: Shrubs with alternate leaves and dicœcious flowers in catkins; perianth minute or 0; pistil 1-celled, 1-ovuled; endosperm minute. (Sp. 3.)

Family **Ceratophyllaceæ** (Hornworts): Aquatic herbs with verticillate, divided leaves; flowers dicœcious; perianth 0; pistil 1-celled, 1-ovuled; endosperm 0. (Sp. 3.)

Family **Piperaceæ** (Peppers): Herbs, shrubs, and trees with alternate (or opposite) leaves; flowers perfect or diclinous, mostly spicate; perianth 0; pistil 1-celled, 1-ovuled; endosperm present. (Sp. 1025.)

Family **Podostemaceæ** (Podostemads): Small aquatic, sometimes thallose, plants; flowers perfect or diclinous; perianth 0; pistil 1- to 3-celled; ovules many; endosperm 0. (Sp. 116.)

Order 48. HETEROMERÆ. Heteromerals.

Flowers usually gamopetalous; pistil of 3 or more united carpels, its ovary generally superior; ovules usually with but one coat; stamens as many or twice as many as the corolla-lobes.

Sub-order Primulales: Flowers regular, mostly perfect; stamens mostly opposite to the corolla-lobes; ovary pluricarpellary, mostly 1-celled, with a free central placenta.

Family **Plumbaginaceæ** (Leadworts): Herbs with alternate or clustered leaves; stamens opposite the petals; ovule 1, basal, anatropous; fruit capsular; dehiscence valvate or irregular. (Sp. 235.)

Family **Plantaginaceæ** (Plantains): Herbs with alternate or clustered leaves; stamens alternate with the petals; ovary mostly 2-celled; ovules many; placentæ axile; fruit a capsule dehiscing circumscissilly. (Sp. 200.)

Family **Primulaceæ** (Primroses): Herbs with alternate or opposite, sometimes clustered, leaves; stamens opposite the petals; ovules many; fruit a capsule dehiscing longitudinally from the apex or circumscissilly. (Sp. 315.)

Family **Myrsinaceæ**: Trees and shrubs with alternate (or opposite) leaves; stamens opposite the petals; ovules usually few; fruit a drupe or berry. (Sp. 550.)

SUB-ORDER ERICALES: Flowers regular, perfect; stamens alternate with the corolla-lobes; cells of the ovary, or placentæ 2 to many; seeds minute.

Family **Vacciniaceæ** (Huckleberries): Shrubs and trees with mostly alternate evergreen leaves; ovary inferior, 2- to 10-celled; fruit fleshy or succulent; anthers dehiscing by an apical pore. (Sp. 230.)

Family **Ericaceæ** (Heaths): Shrubs and trees with alternate opposite or whorled mostly evergreen leaves; ovary superior, 2- to 10-celled; fruit usually a capsule; anthers dehiscing by an apical pore. (Sp. 1080.)

Family **Monotropeæ** (Indian Pipes): Pale, leafless, parasitic herbs; ovary superior, 1- to several-celled; fruit a capsule; anthers dehiscing by a slit. (Sp. 12.)

Family **Epacrideæ** (Epacrids): Shrubs and small trees with mostly alternate evergreen leaves; ovary superior, mostly 2- to 10-celled; fruit capsular or drupaceous; anthers dehiscing by a slit. (Sp. 325.)

Family **Diapensiaceæ**: Low undershrubs with alternate evergreen leaves; ovary superior, 3-celled; fruit a capsule; anthers dehiscing by a slit. (Sp. 9.)

Family **Lennoaceæ**: Parasitic leafless herbs; ovary superior, 10- to 14-carpellary, 20- to 28-celled; ovules solitary; anthers dehiscing by a slit. (Sp. 4.)

SUB-ORDER EBENALES: Flowers regular, perfect, or diclinous; stamens opposite to the corolla-lobes; ovary 2- to many-celled; seeds mostly solitary or few, usually large.

Family **Sapotaceæ** (Star-apples): Trees and shrubs with mostly alternate leaves; flowers mostly perfect; stamens attached to the corolla; ovary superior. (Sp. 400.)

Family **Ebenaceæ** (Ebonyworts): Trees and shrubs with mostly alternate leaves; flowers mostly diœcious; stamens usually free from the corolla; ovary superior. (Sp. 250.)

Family **Styracaceæ** (Storaxworts): Trees and shrubs with alternate leaves; flowers mostly perfect; stamens attached to the corolla; ovary usually inferior. (Sp. 235.)

ORDER 49. **BICARPELLATÆ.** BICARPALS.

Flowers gamopetalous; pistil usually of two united carpels, its ovary generally superior; stamens as many as the corolla-lobes or less.

SUB-ORDER POLEMONIALES: Corolla regular; stamens alternate with the corolla-lobes, and of the same number; leaves mostly alternate.

Family **Polemoniaceæ** (Phloxes): Herbs (and shrubs) with alternate or opposite leaves; corolla-lobes contorted; ovary tricarpellary, 3-celled; ovules 2 or more. (Sp. 150)

Family **Hydrophyllaceæ** (Hydrophylls): Herbs with radical or alternate (rarely opposite) leaves; corolla-lobes imbricated (or contorted); ovary 1- or incompletely 2-celled; ovules 2 or more. (Sp. 130.)

Family **Boraginaceæ** (Borageworts): Herbs, shrubs, and trees with alternate leaves; corolla-lobes imbricated (or contorted); ovary bicarpellary, 4-celled, 4-lobed; ovules solitary. (Sp. 1235.)

Family **Convolvulaceæ** (Morning-glories): Herbs, shrubs (and trees) with alternate leaves; corolla-limb more or less plicate (rarely imbricated); ovary 2- (3- to 5-) celled; ovules few. (Sp. 870.)

Family **Solanaceæ** (Nightshades): Herbs, shrubs (and trees) with alternate leaves; corolla-limb more or less plicate (rarely imbricated); ovary mostly 2-celled; ovules many. (Sp. 1500.)

SUB-ORDER GENTIANLAES: Corolla regular; stamens alternate with the corolla-lobes, and usually of the same number; leaves opposite (rarely alternate).

Family **Oleaceæ** (Olives): Shrubs and trees (rarely herbs) with mostly opposite leaves; corolla-lobes valvate or 0; stamens 2 (or 4); ovary 2-celled; ovules 1 to 3. (Sp. 300.)

Family **Salvadoraceæ**: Shrubs and trees with opposite undivided leaves; corolla-lobes imbricate; stamens 4; ovary 2-celled; ovules 2. (Sp. 8.)

Family **Apocynaceæ** (Dogbanes): Milky-juiced trees, shrubs, and herbs with opposite simple leaves; corolla-lobes contorted or valvate; stamens 5 with granular pollen; ovary 2-celled or the carpels separating; ovules many. (Sp. 1035.)

Family **Asclepiadaceæ** (Milkweeds): Milky-juiced herbs and shrubs with opposite (or alternate) leaves; corolla-lobes contorted; stamens 5 with agglutinated pollen; ovary of two separated carpels; ovules many. (Sp. 1700.)

Family **Loganiaceæ**: Herbs, shrubs, and trees with mostly opposite simple leaves; corolla-lobes imbricated or contorted; stamens 4 to 5 (or indefinite); ovary 2- to 4-celled; ovules 1 to many. (Sp. 365.)

Family **Gentianaceæ** (Gentians): Mostly herbs with mostly opposite undivided leaves; corolla-lobes contorted, valvate, or induplicate; stamens 4 to 5 (or indefinite); ovary usually 1-celled; ovules many. (Sp. 575.)

SUB-ORDER PERSONALES: Corolla mostly irregular or oblique; stamens fewer than the corolla-lobes, usually 4 or 2; ovules numerous; fruit mostly capsular.

Family **Scrophulariaceæ** (Figworts): Herbs (shrubs and small

trees) with alternate opposite or whorled leaves; ovary 2-celled with an axile placenta; seeds with endosperm. (Sp. 2000.)

Family **Orobanchaceæ** (Broom-rapes): Leafless parasitic herbs; ovary 1-celled; placentæ parietal; ovules minute, numerous. (Sp. 150.)

Family **Lentibulariaceæ** (Badder-worts): Aquatic or marsh herbs with radical or alternate leaves; ovary 1-celled with a globose basilar placenta. (Sp. 200.)

Family **Columelliaceæ**: Trees and shrubs with opposite evergreen leaves; ovary 2-celled, with an axile placenta. (Sp. 2.)

Family **Gesneraceæ**: Herbs, shrubs (and trees) with usually opposite leaves; ovary 1-celled with 2 parietal placentæ; seeds numerous; endosperm scanty or 0. (Sp. 960.)

Family **Bignoniaceæ** (Bignoniads): Trees, shrubs (and herbs) with opposite or whorled leaves; ovary 1- or 2-celled with parietal or axile placentæ; seeds numerous without endosperm. (Sp. 500.)

Family **Pedaliaceæ**: Herbs with mostly opposite leaves; ovary 1-, 2, or 4-celled with parietal or axile placentæ; seeds 1 to many without endosperm. (Sp. 46.)

Family **Acanthaceæ** (Acanths): Herbs (shrubs and trees) with opposite leaves; ovary 2 celled; placentæ axile; seeds 2 to many without endosperm. (Sp. 1500.)

SUB-ORDER LAMIALES. Corolla mostly irregular or oblique; stamens fewer than the corolla-lobes, usually 4 or 2; ovules mostly solitary; fruit indehiscent.

Family **Myporineæ**: Shrubs and trees with usually alternate leaves; flowers axillary. (Sp. 78.)

Family **Selagineæ**: Heath-like shrubs or low herbs with mostly alternate leaves; flowers small, in terminal spikes or heads. (Sp. 140.)

Family **Verbenaceæ** (Verbenas): Herbs, shrubs, and trees with usually opposite leaves, stigma usually undivided. (Sp. 740.)

Family **Labiatæ** (Mints): Mostly aromatic herbs, shrubs (and trees) with opposite or whorled leaves; stigma usually bifid. (Sp. 2700.)

ORDER 50. CALYCIFLORÆ. CALYCALS.

Calyx usually of united sepals; petals separate, and with the stamens inserted on the calyx or the adherent disk; ovary superior in the lower, and inferior in the higher, families.

SUB-ORDER ROSALES. Flowers usually perfect, regular or irregular; pistils separate or more or less united, sometimes united with the calyx-tube; styles usually distinct.

Family **Connaraceæ**: Trees and shrubs with alternate compound

leaves ; stamens definite ; pistils 1 to 5, free ; ovules 2, ascending, orthotropous. (Sp. 170.)

Family **Rosaceæ** (Roseworts) : Herbs, shrubs, and trees with mostly alternate leaves ; stamens usually indefinite ; pistils 1 to many, free (or coalesced and inferior) ; ovules usually 2, anatropous. (Sp. 1000.)

Family **Mimosaceæ** (Mimosas) : Trees, shrubs (and herbs) with alternate, pinnately compound leaves, often reduced to phyllodes ; flowers regular ; petals valvate ; stamens mostly indefinite, usually free ; pistils monocarpellary, usually 1 (rarely 5 to 15) ; ovules anatropous. (Sp. 1350.)

Family **Cæsalpiniaceæ** (Brasilettos) : Trees, shrubs, and herbs with mostly alternate, pinnately compound leaves ; flowers mostly irregular ; petals imbricate ; stamens 10 or less, usually free ; pistil 1, monocarpellary ; ovule anatropous. (Sp. 940.)

Family **Papilionaceæ** (Beans) : Trees, shrubs, and herbs, with mostly alternate, simple or compound, often tendril bearing leaves flowers irregular (papilionaceous) ; petals imbricate ; stamens usually 10, commonly monadelphous or diadelphous ; pistil 1, monocarpellary ; ovules amphitropous. (Sp. 4700.)

Family **Saxifragaceæ** (Saxifrages) : Herbs, shrubs, and trees with alternate or opposite leaves ; stamens mostly definite ; pistils usually compound ; ovules indefinite. (Sp. 650.)

Family **Crassulaceæ** (Crassulas) : Mostly fleshy herbs with opposite or alternate leaves ; stamens definite ; pistils several, free or little united , ovules indefinite. (Sp. 485.)

Family **Droseraceæ** (Sundews) : Gland-bearing marsh herbs ; stamens mostly definite ; pistil syncarpous, 1- to 3-celled, superior ; ovules many, on basal, axile, or parietal placentæ. (Sp. 105.)

Family **Hamamelidaceæ** (Witch-hazels) : Shrubs and trees with mostly alternate leaves ; stamens few or many ; pistil bicarpellary, its ovary inferior ; ovules solitary or many. (Sp. 40.)

Family **Bruniaceæ** : Heath like shrubs with small leaves ; stamens definite ; pistil mostly 3-celled, inferior to superior ; ovules 1 to many, pendulous. (Sp. 45.)

Family **Halorageæ** (Hippurids) : Aquatic or terrestrial herbs with mostly alternate leaves ; pistil 1- to 4 celled, inferior ; ovules solitary, pendulous. (Sp. 85.)

SUB-ORDER MYRTALES : Flowers regular or nearly so, usually perfect ; pistil of united carpels, usually inferior ; placentæ axile or apical (rarely basal) ; style 1 (rarely several) ; leaves simple, usually entire.

Family **Rhizophoraceæ** (Mangroves) : Trees and shrubs with mostly opposite leaves ; stamens 2 to 4 times the number of petals ; pistil 2- to 6-celled, usually inferior ; ovules 2, pendulous. (Sp. 50.)

Family **Combretaceæ**: Trees and shrubs with opposite or alternate leaves; stamens usually definite; pistil 1-celled, inferior; ovules 2 to 6 or solitary, pendulous. (Sp. 280.)

Family **Myrtaceæ** (Myrtles): Trees and shrubs with opposite or alternate leaves; stamens indefinite; pistil 2- to many-celled, inferior; ovules 2 to many; placentæ basal or axile. (Sp. 2100.)

Family **Melastomaceæ** (Melastomads): Herbs, shrubs, and trees with mostly opposite leaves; stamens usually double the number of petals; pistil 2 to many-celled, free or adherent to the calyx-tube; ovules minute, numerous, on axile or parietal placentæ. (Sp. 2500.)

Family **Lythraceæ** (Lythrads): Herbs, shrubs, and trees usually with opposite leaves and 4-angled branches; stamens definite or indefinite; pistil 2- to 6-celled, free; ovules numerous, on axile placentæ. (Sp. 365.)

Family **Onagraceæ** (Onagrads): Herbs (shrubs and trees) with opposite or alternate leaves; stamens 1 to 8, rarely more; pistil usually 4-celled, inferior; ovules 1 to many on axile placentæ. (Sp. 330.)

Family **Aristolochiaceæ** (Birthworts): Herbaceous or shrubby plants with alternate leaves; petals absent; stamens 6, rarely more; pistil 4- or 6-celled, inferior; ovules numerous, on axile (or protruding parietal) placentæ. (Sp. 225.)

Family **Cytinaceæ** (Vine-rapes): Fleshy parasitic herbs, leafless or nearly so; petals 4 or 0; stamens 8 to many; pistil 1-celled or imperfectly many-celled, inferior; ovules minute, very numerous, on parietal or pendulous, folded placentæ. (Sp. 27.)

Sub order Passiflorales: Flowers usually regular, perfect or diclinous; pistil syncarpous, 1-celled, its ovary usually inferior; placentæ parietal; styles free or connate, leaves ample, entire, lobed, or dissected.

Family **Loasaceæ**: Herbs with opposite or alternate leaves; flowers perfect; sepals and petals dissimilar; stamens indefinite; ovary inferior; endosperm fleshy or 0. (Sp. 115.)

Family **Turneraceæ**: Herbs and shrubs with alternate leaves; flowers perfect; sepals and petals dissimilar; stamens definite; ovary free; endosperm copious. (Sp. 85.)

Family **Passifloraceæ** (Passion-flowers): Climbing herbs, and shrubs (a few trees) with alternate leaves; flowers perfect; sepals and petals similar; stamens definite; ovary free; endosperm fleshy. (Sp. 235.)

Family **Cucurbitaceæ** (Cucurbits): Mostly climbing or prostrate herbs and undershrubs with alternate leaves; flowers diclinous; stamens definite (usually 3); ovary inferior; endosperm 0. (Sp. 633.)

Family **Begoniaceæ** (Begoniads): Mostly herbs with alternate

leaves; flowers diclinous; stamens indefinite; ovary inferior, usually 3-angular; endosperm little or 0. (Sp. 425.)

Family **Datiscaceæ**: Herbs or trees with alternate leaves; flowers mostly diclinous; stamens 4 to many; ovary inferior, usually gaping at the top; endosperm scanty. (Sp. 4.)

SUB-ORDER CACTALES: Flowers regular or nearly so, perfect; pistil syncarpous, 1-celled, with parietal placentæ, its ovary inferior; style divided at the apex; endosperm present or 0; embryo curved; fleshy-stemmed, mostly leafless, plants.

Family **Cactaceæ** (Cactuses): With the characters of the sub-order. (Sp. 1100.)

SUB-ORDER CELASTRALES: Receptacle developing a glandular, annular, or turgid disk, which is sometimes adnate to the calyx-tube or the pistil (sometimes the disk is rudimentary or wanting); pistil 1- to many-celled (rarely apocarpous); ovules 1 to 3, pendulous or erect; endosperm present or 0.

Family **Olacaceæ** (Olacads): Trees and shrubs with usually alternate simple leaves; disk free or adnate to the calyx; petals present; pistil 1- to 3-celled; ovules 2 to 3, pendulous; endosperm fleshy. (Sp. 277.)

Family **Ilicineæ** (Hollies): Trees and shrubs with alternate or opposite simple leaves; disk obsolete; pistil 3- to many-celled; ovule 1, pendulous; endosperm fleshy. (Sp. 181.)

Family **Celastraceæ** (Bitter-sweets): Shrubs and trees with usually alternate simple leaves; disk fleshy; petals present; pistil 2- to 5-celled; ovules usually 2, erect or pendulous; endosperm fleshy. (Sp. 455.)

Family **Stackhousieæ**: Herbs with simple alternate leaves; disk thin, on the base of the calyx; petals present; ovary 2- to 5-celled; ovule 1, erect; endosperm fleshy. (Sp. 21)

Family **Rhamnaceæ** (Buckthorns): Trees and shrubs with usually alternate simple leaves; disk adnate to the calyx; petals present; pistil 2- to 4-celled; ovules 1 or 2, erect; endosperm fleshy. (Sp. 475.)

Family **Ampelideæ** (The Vines): Shrubs and trees with alternate, simple or compound leaves; disk adnate to the calyx; petals coherent, valvate; pistil 2-celled, 2 ovuled (or 3–6-celled, 1-ovuled); endosperm often ruminate. (Sp. 435.)

Family **Lauraceæ** (Laurels): Aromatic trees and shrubs with alternate simple leaves; disk 0; petals 0; ovule 1, pendulous; endosperm 0. (Sp. 900.)

Family **Proteaceæ** (Proteads): Shrubs, trees (and herbs) with scattered, simple, usually coriaceous leaves; disk 0; petals 0; pistil 1-celled; ovule 1, erect or pendulous; endosperm little or none. (Sp. 950.)

Family **Thymelæaceæ** (Daphnads): Shrubs, small trees (and herbs) with scattered or opposite, usually coriaceous, simple leaves; disk 0; petals 0; pistil 1-celled; ovule 1, pendulous; endosperm fleshy, copious, sparse, or 0. (Sp. 400.)

Family **Penæaceæ**: Evergreen heath-like shrubs with small opposite leaves; disk 0; petals 0; pistils 4-celled; ovules 2, erect; endosperm 0. (Sp. 20.)

Family **Elæagnaceæ** (Oleasters): White- or brown-scurfy trees and shrubs with alternate or opposite simple leaves; disk lining the perianth-tube; petals 0; pistil 1-celled; ovule 1, ascending; endosperm 0 or scanty. (Sp. 31.)

Family **Santalaceæ** (Sandalworts): Parasitic herbs, shrubs, and trees with alternate or opposite simple leaves; disk epigynous; petals 0; pistil 1-celled; ovules 2 to 5, pendulous; endosperm present. (Sp. 200.)

Family **Loranthaceæ** (Loranths): Parasitic herbs or shrubs with opposite or alternate leaves, often reduced to bracts; disk epigynous; petals 0; pistil 1-celled, inferior; ovules 1, erect; endosperm present. (Sp. 520.)

Family **Balanophoraceæ**: Parasitic leafless herbs, monœcious or diœcious; disk 0; petals 0; pistil 1-celled, inferior; ovule 1, erect; endosperm present. (Sp. 37.)

SUB-ORDER SAPINDALES: Disk tumid, adnate to the calyx, lining its tube or rudimentary, or entirely wanting; pistils 1- to several-celled; ovules 1 to 2, erect, ascending, or pendulous; endosperm mostly 0.

Family **Sapindaceæ** (Soapworts): Trees and shrubs with alternate (or opposite) mostly, compound, leaves; disk present or 0; petals 3 to 5 or 0; pistil 1- to 4-celled; ovules 1 or 2, ascending; endosperm usually 0. (Sp. 1078)

Family **Sabiaceæ**: Trees and shrubs with alternate simple or compound leaves; disk small; petals present; pistil 2- to 3-celled; ovules 1 or 2, horizontal or pendulous; endosperm 0. (Sp. 40.)

Family **Anacardiaceæ** (Sumachs): Trees and shrubs with alternate, usually compound, leaves; disk usually annular; petals 3 to 7 or 0; pistil 1- to 5-celled; ovules solitary, pendulous (or erect); endosperm scanty or 0. (Sp. 430.)

Family **Juglandaceæ** (Walnuts): Trees and shrubs with alternate compound leaves; disk forming a capsule; pistil 1-celled, inferior; ovule 1, erect, orthotropous; endosperm 0. (Sp. 35.)

Family **Cupuliferæ** (Oaks): Trees and shrubs with alternate simple leaves; disk 0; petals 0; pistil 2- to 6-celled, inferior; ovules 2, erect or pendulous; endosperm 0. (Sp. 420.)

Family **Myricaceæ** (Galeworts): Shrubs and trees with alternate simple leaves; disk 0; petals 0; pistil free, 1-celled; ovule 1, erect, orthotropous; endosperm 0. (Sp. 40.)

Family **Casuarinaceæ** (Beefwoods): Shrubs and trees with striate stems bearing whorls of reduced scale-like leaves; disk 0; petals 0; pistil 1-celled; ovules 2, lateral, half anatropous; endosperm 0. (Sp. 23.)

SUB-ORDER UMBELLALES: Flowers regular, usually perfect; stamens usually definite; pistil syncarpous, 1- to many-celled, its ovary inferior; ovules solitary, pendulous; styles free or united at the base; endosperm copious; embryo usually minute.

Family **Umbelliferæ** (Umbellifers): Herbs (shrubs and trees) with alternate leaves; flowers small, mostly umbellate; ovary 2-celled; fruit splitting into two dry indehiscent mericarps. (Sp. 1400.)

Family **Araliaceæ** (Ivyworts): Trees, shrubs (and herbs) with alternate leaves; flowers in umbels, heads, or panicles; ovary 2- to 15-celled; fruit a berry with a fleshy or dry exocarp. (Sp. 375.)

Family **Cornaceæ** (Cornels): Shrubs and trees (rarely herbs) with usually opposite leaves; flowers umbellate, capitate, or corymbose; ovary 2- to 4-celled; fruit drupaceous. (Sp. 80.)

ORDER 51. **INFERÆ**. INFERALS.

Pistil of two or more carpels, united, its ovary inferior; stamens usually as many as the corolla-lobes, mostly attached to the corolla.

SUB-ORDER RUBIALES: Flowers regular or irregular; stamens attached to the corolla; ovary 2- to 8-celled; ovules 2 to many.

Family **Caprifoliaceæ** (Honeysuckles): Flowers usually irregular with imbricate corolla-lobes; style usually with a capitate undivided stigma; fruit a berry. (Sp. 240.)

Family **Rubiaceæ** (Madderworts): Trees, shrubs, and herbs with opposite or whorled leaves; flowers usually regular with valvate, contorted, or imbricate corolla-lobes; style simple, bifid, or multifid; fruit a capsule, berry, or drupe. (Sp. 4500.)

SUB-ORDER CAMPANALES: Flowers mostly irregular; stamens usually free from the corolla; ovary 1- to many-celled; ovules 1 to 8.

Family **Candolleaceæ**: Herbs with tufted, radical, and scattered stem-leaves; flowers usually irregular; stamens 2, connate with the style. (Sp. 105.)

Family **Goodenovieæ**: Herbs and shrubs with alternate (or opposite) leaves; flowers usually irregular; stamens 5, free from the style. (Sp. 210.)

Family **Campanulaceæ** (Bellworts): Mostly milky-juiced herbs (shrubs and small trees) with alternate (or opposite) leaves; flowers regular or irregular; stamens usually 5, free from the style. (Sp. 1080.)

SUB-ORDER ASTERALES: Flowers regular or irregular; stamens

attached to the corolla, their anthers mostly connate ; ovary 1-celled, 1-ovuled.

Family **Valerianaceæ**: Herbs (and shrubs) with opposite leaves ; flowers cymose, corymbose, or solitary ; anthers free ; ovules pendulous. (Sp. 275.)

Family **Dipsaceæ** (Teaselworts): Herbs (and shrubs) with opposite or whorled leaves ; flowers in involucrate heads ; anthers free ; ovule pendulous. (Sp. 150.)

Family **Calyceraceæ**: Herbs with alternate leaves ; flowers in involucrate heads anthers connate ; ovule pendulous. (Sp. 23.)

Family **Compositæ** (Composites): Herbs, shrubs (and trees) with opposite or alternate leaves ; flowers in involucrate heads ; anthers connate ; ovule erect. (Sp. 10,200.)

Systematic Literature —There is no complete Flora of the Angiosperms of the United States. The gamopetalous families have been completed in Gray's "Synoptical Flora of North America." For the remaining flowering plants we must make use of the various local Floras, as follows :

For the Northeastern United States (i.e., north of North Carolina and Tennessee, and west to the 100th meridian), Gray's "Manual of Botany" (6th edition).

For the Southeastern United States (i.e., south of the preceding, and west to the Mississippi River), Chapman's "Flora of the Southern United States."

For the Pacific coast region of the United States, Watson's "Botany of California," Rattan's "Popular California Flora," Greene's "Manual of the Bay Region Botany."

For the Rocky Mountains and the Plains, Coulter's "Manual of Rocky Mountain Botany."

For Western Texas and the adjacent parts of New Mexico, Coulter's "Flora of Western Texas."

The Great Basin of Utah and Nevada, and the Arizona region, have no manuals as yet. For these Watson's and Rothrock's reports will render good service.

The student may profitably consult Bentham and Hooker's "Genera Plantarum," De Candolle's "Prodromus," and Engler and Prantl's "Natürlichen Pflanzenfamilien."

APPENDIX.

BOOK-LIST.

Full titles of the works cited in this book are given below, with place of publication and approximate prices :

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